Analysis of Insufficient Glue Defects In The Die Attach Process

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***Abstract*—The die attach process is one of the critical stages in semiconductor packaging, where adhesive quality directly affects product reliability and manufacturing yield. One of the major quality issues is the occurrence of Insufficient Glue defects, which can lead to poor die adhesion and product failure. This study aims to analyze the root causes of Insufficient Glue defects in the Die Attach process on the DAG 142 machine. The research applies the Fishbone Diagram method to identify potential causes based on the aspects of Man, Machine, Method, Material, Measurement, and Environment. Production data and direct observations were analyzed to determine the dominant factors contributing to the defect. The analysis indicates that machine conditions, improper process parameters, and inadequate maintenance practices are the primary contributors to the occurrence of Insufficient Glue defects. The proposed corrective actions are expected to improve process stability, reduce defect rates, and increase production yield while supporting continuous quality improvement in semiconductor manufacturing.**

Keywords: Die Attach Process, Fishbone Diagram, Insufficient Glue, Root Cause Analysis, Semiconductor Manufacturing, Quality Improvement.

II. INTRODUCTION

The semiconductor manufacturing industry demands high product quality and process reliability to meet increasingly stringent customer requirements. One of the critical assembly processes in semiconductor packaging is the die attach process, where semiconductor chips are bonded onto lead frames or substrates using conductive or non-conductive adhesive materials. The quality of this process directly affects product reliability, electrical performance, and manufacturing yield. Any deviation during adhesive dispensing or die placement may result in defects that reduce production efficiency and increase manufacturing costs. [1]

One of the common defects encountered in the die attach process is Insufficient Glue, which occurs when the amount of adhesive applied to the die is below the required specification. This defect may reduce bonding quality, affect package reliability, and increase the risk of product failure. Therefore, identifying its root causes is essential for improving process capability and maintaining manufacturing quality. Therefore, identifying the root causes of insufficient glue defects is essential to improve process capability and ensure product quality.

The Insufficient Glue defect is a condition in which the amount of epoxy adhesive dispensed onto the leadframe is lower than the required specification, resulting in incomplete adhesive coverage beneath the semiconductor die. Since the epoxy serves as the primary bonding medium between the die and the leadframe, insufficient adhesive volume may compromise the mechanical strength and thermal performance of the semiconductor package.[2]

In the Die Attach process, adequate epoxy coverage is essential to provide sufficient bonding support between the semiconductor die and the leadframe. When the dispensed epoxy volume is insufficient, part of the die may not be fully supported, increasing the possibility of package reliability degradation during subsequent manufacturing processes.

The Insufficient Glue defect is primarily detected through the Post Epoxy Inspection system integrated into the Die Attach machine and verified through microscope observation when necessary. The inspection evaluates whether the epoxy coverage satisfies the predefined acceptance criteria. Units that do not meet the required coverage are classified as Insufficient Glue defects and rejected for further processing.

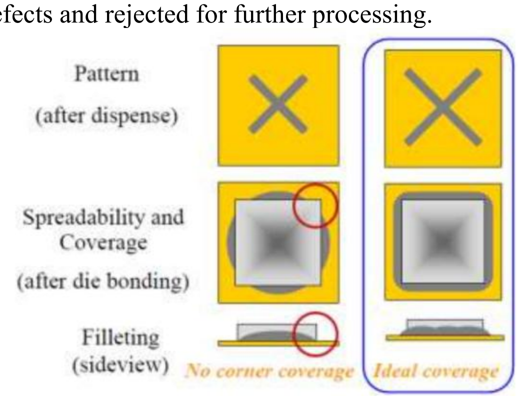


Figure 1. Acceptable and Insufficient Glue Conditions

Figure 1 presents an illustration of acceptable epoxy coverage and the Insufficient Glue defect condition. The acceptable condition shows adequate adhesive distribution beneath the die, while the defective condition exhibits incomplete epoxy coverage that may affect bonding quality and product reliability.[3]

Based on production quality records, Insufficient Glue was identified as one of the recurring defects in the Die Attach process on the DAG 142 machine. Production alarm records showed frequent occurrences of Error 652 (Insufficient Epoxy Coverage) and Error 280 (Epoxy Size Too Small), both of which are directly related to insufficient epoxy dispensing. Among the observed Die Attach machines, DAG142 exhibited one of the highest occurrences of epoxy-related alarms and was therefore selected as the object of this study. Figure 2 presents the distribution of epoxy-related machine alarms before corrective actions were implemented.

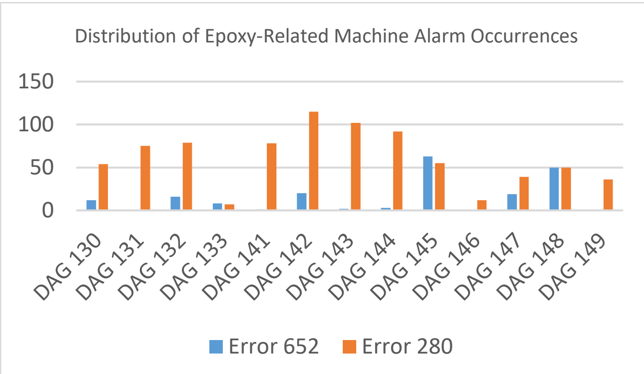


Figure 2. Distribution of Epoxy-Related Machine Alarm Occurrences

Several previous studies have investigated defect analysis and quality improvement in semiconductor manufacturing using various quality management tools such as Statistical Process Control (SPC), Failure Mode and Effects Analysis (FMEA), Fishbone Diagram, and the 5 Why Analysis. These methods have proven effective in identifying process deviations and proposing corrective actions. However, most previous studies focus on general production defects or multiple process stages, while limited research specifically investigates insufficient glue defects occurring in the die attach process under actual production conditions.

This research focuses on analyzing the Insufficient Glue defect occurring in the Die Attach process using the Fishbone Diagram method. The study is conducted on the DAG 142 machine, where defect occurrences have significantly affected production yield. By systematically identifying potential causes from the aspects of Man, Machine, Method, Material, Measurement, and Environment, the study aims to determine the dominant root causes, implement appropriate corrective actions, and evaluate their effectiveness in reducing the occurrence of Insufficient Glue defects.

The results of this research are expected to provide practical recommendations for reducing Insufficient Glue defects, improving process stability, increasing production yield, and supporting continuous quality improvement in semiconductor manufacturing. Furthermore, this study contributes to the application of root cause analysis techniques for solving manufacturing quality problems in the semiconductor packaging industry.

III. METHOD

A. Design

This research employed a descriptive analytical approach to investigate the occurrence of Insufficient Glue defects in the Die Attach process. The study was conducted in the semiconductor assembly production line, focusing on the DAG 142 Die Attach machine, where the defect frequently occurred during the manufacturing process.

The research aimed to identify the root causes of Insufficient Glue defects by analyzing production data, observing the actual manufacturing process, and evaluating factors that influence adhesive dispensing performance. Based on the identified root causes, corrective actions were implemented through parameter optimization and verification activities to improve epoxy dispensing performance. The analysis was carried out using the Fishbone Diagram (Cause-and-Effect Diagram), which classifies potential causes into six categories: Man, Machine, Method, Material, Measurement, and Environment (6M).

The overall research consisted of problem identification, production data collection, process observation, Fishbone Diagram analysis, verification of potential root causes, implementation of corrective actions through parameter optimization, and evaluation of the implemented improvements using inspection results before and after corrective action. This systematic approach was adopted to determine the dominant root causes and evaluate the effectiveness of the implemented improvement.

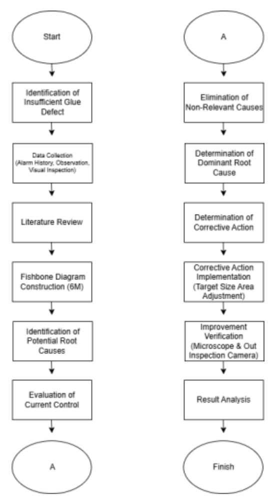


Figure 3. Flowchart of Design

Figure 3 illustrates the overall research procedure, beginning with problem identification, followed by production data collection, process observation, Fishbone Diagram analysis, verification of root causes, implementation of corrective actions, and evaluation of the improvement results.

B. Die Attach Process

The Die Attach process is a critical stage in semiconductor assembly in which a semiconductor die is bonded onto a leadframe using epoxy adhesive. The process establishes the mechanical attachment and thermal path between the die and the package structure, directly affecting product reliability and performance.[4]

In the production line, the Die Attach process is performed using the DAG 142 machine. Prior to production, machine readiness and dispensing parameters, including epoxy volume, dispensing pressure, and dispensing position, are verified to ensure process consistency. During production, epoxy adhesive is dispensed onto the leadframe before the semiconductor die is accurately placed on the adhesive surface. Machine conditions, nozzle performance, glue condition, and material availability are continuously monitored to maintain stable production and minimize process abnormalities.

After die placement, the assembled units undergo Post Epoxy Inspection to evaluate epoxy coverage beneath the die. When necessary, additional verification using microscope observation is performed to confirm the epoxy coverage condition. Units that fail to satisfy the required inspection criteria are classified as No Good (NG) and recorded for further analysis.[5]

The overall Die Attach process flow adopted in this study is illustrated in Figure 2.

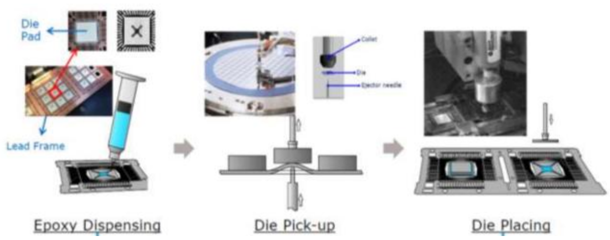


Figure 4. Die Attach Process

Figure 4 illustrates the Die Attach process flow, including machine preparation, parameter verification, epoxy dispensing, die placement, and inspection activities. Since Insufficient Glue defects originate during epoxy dispensing, the dispensing process and subsequent inspection stages were selected as the primary focus of this study.[6]

C. *Electrically Conductive Epoxy in Die Attach*

In the die attach process, the glue used is not a conventional adhesive, but an electrically conductive adhesive specifically formulated for semiconductor applications. This glue performs three main functions, namely as a mechanical bonding material, an electrical conduction path, and a thermal conduction path between the die and the leadframe.

The glue acts as an interface material between the die and the leadframe; therefore, the quality and distribution of the glue directly affect product performance and reliability. For this reason, control of dispensing parameters and glue condition becomes a critical factor in the electronics manufacturing process.

C.1 Functional Properties of Conductive Epoxy

The epoxy adhesive used in the Die Attach process functions not only as a bonding material between the semiconductor die and the leadframe but also as an interface material that contributes to the functional performance of the semiconductor package. In electronic packaging, conductive epoxy can provide mechanical attachment, electrical conduction, and thermal transfer between the die and the leadframe. Therefore, the properties of the epoxy material are important in determining the quality and reliability of the die attach interface.

The adhesive material used in the Die Attach process investigated in this study is TS333LD-H35N, a silver-filled electrically conductive adhesive. The presence of conductive filler enables the adhesive to provide electrical conduction while maintaining its function as a bonding material. Therefore, TS333LD-H35N can be considered as an interface material with combined electrical, thermal, and mechanical functions in the die attach structure.

These functions are directly related to the condition of the adhesive interface formed during the Die Attach process. Consequently, an insufficient adhesive condition may not only affect the physical attachment of the die but may also reduce the effective interface available for electrical conduction and heat transfer.

C.2 Electrical, Thermal, and Mechanical Properties TS333LD-H35N

The electrically conductive epoxy used in the Die Attach process investigated in this study is TS333LD-H35N manufactured by Tanaka Kikinzoku Kogyo K.K. The material is a silver-filled electrically conductive adhesive used as the interface between the semiconductor die and the leadframe.

The material properties used in this study were obtained from the Technical Data Sheet (TDS/PDS) of TS333LD-H35N. The relevant material properties are summarized in Table I.

Property	**Parameter**	**Value**
Viscosity	—	45 Pa·s
Thixotropic Index	V_{10}/V_{50}	2.9
Solid Content	—	90.0 wt%
Silver Content	In paste	83.0 wt%
Silver Content	After curing	92.0 wt%
Electrical	Volume resistivity	20 μΩ·cm
Mechanical	Die shear strength	100 N/mm²
Thermal	Thermal conductivity	25 W/m·K
Mechanical	E-modulus at 25°C	8200 MPa
Mechanical	E-modulus at 200°C	1800 MPa
Thermal	Tg	115°C
Thermal	CTE α1	27 ppm/°C
Thermal	CTE α2	15 ppm/°C

Tabel I. Technical Properties of TS333LD-H35N

The volume resistivity of 20 μΩ·cm indicates the electrical conduction capability of the silver-filled epoxy. The thermal conductivity of 25 W/m·K indicates the ability of the adhesive layer to transfer heat through the die attach interface. Meanwhile, the representative die shear strength of 100 N/mm² indicates the mechanical bonding capability of the adhesive.

In addition to the technical properties, the Safety Data Sheet (SDS/MSDS) of TS333LD-H35N is used as the reference for material safety, handling, storage, and personal protective equipment requirements. The SDS/MSDS is included as a supporting material document in the research documentation.

The technical properties presented in this section are used to support the theoretical analysis of the relationship between epoxy coverage and the functional role of the die attach interface. However, the electrical, thermal, and mechanical properties are not directly measured as experimental responses in this study. The experimental evaluation focuses on the epoxy coverage obtained from the Post Epoxy Inspection system and microscope observation.

C.3 Relationship Between Epoxy Coverage and Insufficient Glue

The functional performance of conductive epoxy is influenced not only by the intrinsic properties of the adhesive material but also by the effective interface area formed between the semiconductor die and the leadframe. Epoxy coverage represents the percentage of the die area that is covered by epoxy. Therefore, a reduction in epoxy coverage results in a reduction in the effective interface area available for mechanical bonding, electrical conduction, and thermal transfer.

In this study, the die area is 3.28 mm² and the Bond Line Thickness (BLT) is 125 µm. The BLT is converted into millimeters as follows:

$$\boldsymbol{BLT = 125\,\mu m = 0.125\,mm}$$

The theoretical epoxy volume for complete coverage can be calculated using Equation (1):

$$\boldsymbol{V_{epoxy} = A_{die} \times BLT}$$

Where V_{epoxy} is the theoretical epoxy volume (mm³), A_{die} is the die area (mm²), and (BLT) is the Bond Line Thickness (mm).

For 100% epoxy coverage, the theoretical epoxy volume is:

$$V_{100\%} = 3.28\,X\,0.125$$

$$\boldsymbol{V_{100\%} = 0.410\,mm^3}$$

Therefore, the theoretical epoxy volume corresponding to 100% coverage of the die area at a BLT of 125 µm is 0.410 mm³.

For partial epoxy coverage, the effective epoxy area can be calculated using Equation (2):

$$\mathbf{A}_{epoxy} = \mathbf{(C / 100)} \times \mathbf{A}_{die} \qquad (2)$$

where A(epoxy) is the effective epoxy-covered area (mm²), C is the epoxy coverage percentage (%), and A_{die} is the total die area (mm²).

The corresponding theoretical epoxy volume for a given coverage can then be calculated using Equation (3):

$$\mathbf{V}_{epoxy} = \mathbf{A}_{epoxy} \times \mathbf{BLT} \qquad (3)$$

Using Equations (2) and (3), the theoretical effective area and epoxy volume can be compared for 100%, 90%, and 50% coverage. The 100% condition represents complete epoxy coverage, while 90% represents the minimum epoxy coverage acceptance criterion configured in the Post Epoxy Inspection (PEI) system. The 50% condition is used as an illustrative partial-coverage condition to demonstrate the effect of a significant reduction in epoxy coverage. The 50% condition is not an experimental result obtained during production.

For 90% coverage:

$A_{90\%} = 0.90 \times 3.28$
$A_{90\%} = 2.952$ mm²
$V_{90\%} = 2.952 \times 0.125$
$V_{90\%} =$ **0.369 mm³**

For 50% coverage:

$A_{50\%} = 0.50 \times 3.28$
$A_{50\%} = 1.640$ mm²
$V_{50\%} = 1.640 \times 0.125$
$V_{50\%} =$ **0.205 mm³**

The comparison of the theoretical epoxy coverage conditions is presented in Table II.

Coverage Condition	**Effective Epoxy Area (mm²)**	**Theoretical Epoxy Volume (mm³)**
100%	3.280	0.410
90%	2.952	0.369
50%	1.640	0.205

Tabel II. Theoretical Epoxy Area and Volume at Different Coverage Conditions

The calculation demonstrates that the effective epoxy area and theoretical epoxy volume decrease proportionally with the reduction in epoxy coverage when the die area and BLT are maintained constant. At 100% coverage, the entire die area of 3.28 mm² is covered by epoxy, resulting in a theoretical epoxy volume of 0.410 mm³. At the 90% acceptance level, the effective covered area decreases to 2.952 mm² with a theoretical epoxy volume of 0.369 mm³. When the coverage is reduced to 50%, the effective covered area decreases to 1.640 mm² and the theoretical epoxy volume decreases to 0.205 mm³.

The reduction in effective epoxy area also affects the theoretical electrical and thermal characteristics of the die attach interface. For the electrical interface, the resistance of a conductive path can be expressed using Equation (4):

$$\mathbf{R = (\rho \times L) / A} \qquad (4)$$

where R is electrical resistance (Ω), ρ is volume resistivity (Ω·m), L is the conduction path length (m), and A is the effective cross-sectional area (m²).

The volume resistivity of TS333LD-H35N is 20 µΩ·cm, which is equivalent to:

$$\boldsymbol{\rho = 2.0 \times 10^{-7}\ \Omega\cdot m}$$

Assuming that the BLT represents the effective conduction path length, the electrical resistance can be theoretically compared for different epoxy coverage conditions.

For 100% coverage:

$A_{100\%} = 3.28 \times 10^{-6}$ m²
$L = 125 \times 10^{-6}$ m
$R_{100\%} = [(2.0 \times 10^{-7}) \times (125 \times 10^{-6})] / (3.28 \times 10^{-6})$
$R_{100\%} = 7.62 \times 10^{-6}\ \Omega = 7.62\ \mu\Omega$

For 90% coverage:

$A_{90\%} = 2.952 \times 10^{-6}$ m²
$R_{90\%} = [(2.0 \times 10^{-7}) \times (125 \times 10^{-6})] / (2.952 \times 10^{-6})$
$R_{90\%} = 8.47\ \mu\Omega$

For 50% coverage:

$A_{50\%}$ = 1.640 × 10^{-6} m²

$R_{50\%}$ = [(2.0 × 10^{-7}) × (125 × 10^{-6})] / (1.640 × 10^{-6})

$R_{50\%}$ = 15.24 μΩ

These calculations theoretically indicate that reducing the epoxy coverage from 100% to 50% increases the electrical resistance from approximately 7.62 μΩ to 15.24 μΩ, assuming that the material resistivity and conduction path length remain constant.

A similar relationship can be applied to the thermal interface. The thermal resistance can be simplified using Equation (5):

$$\boldsymbol{R_{(th)}} = \mathbf{L / (k \times A)} \qquad (5)$$

where $R_{(th)}$ is thermal resistance (K/W), L is the thermal path length (m), k is thermal conductivity (W/m·K), and A is the effective thermal transfer area (m²).

Using the thermal conductivity of TS333LD-H35N of 25 W/m·K and the same BLT of 125 μm, the theoretical thermal resistance at ***100% coverage is***:

$R_{(th,100\%)}$ = (125 × 10^{-6}) / [25 × (3.28 × 10^{-6})]

$R_{(th,100\%)}$ = 1.524 K/W

For 90% coverage:

$R_{(th,90\%)}$ = (125 × 10^{-6}) / [25 × (2.952 × 10^{-6})]

$R_{(th,90\%)}$ = 1.694 K/W

For 50% coverage:

$R_{(th,50\%)}$ = (125 × 10^{-6}) / [25 × (1.640 × 10^{-6})]

$R_{(th,50\%)}$ = 3.049 K/W

The theoretical calculation indicates that a reduction in epoxy coverage increases the thermal resistance of the die attach interface. The thermal resistance increases from approximately 1.524 K/W at 100% coverage to 3.049 K/W at 50% coverage because the effective thermal transfer area is reduced.

For mechanical bonding, the effective bonding area also decreases when epoxy coverage is reduced. Based on the representative die shear strength of 100 N/mm², the theoretical shear load capacity can be estimated using Equation (6):

$$F_{(max)} = \boldsymbol{\tau} \times \mathbf{A} \qquad (6)$$

where $F_{(max)}$ is the theoretical shear load capacity (N), τ is the die shear strength (N/mm²), and A is the effective epoxy bonding area (mm²).

For 100% coverage:

$F_{100\%}$ = 100 × 3.28

$F_{100\%}$ = 328 N

For 90% coverage:

$F_{90\%}$ = 100 × 2.952

$F_{90\%}$ = 295.2 N

For 50% coverage:

$F_{50\%}$ = 100 × 1.640

$F_{50\%}$ = 164 N

The theoretical results indicate that a reduction in epoxy coverage reduces the effective area available for mechanical load transfer. Therefore, compared with complete coverage, partial epoxy coverage provides a smaller effective bonding area between the die and leadframe.

Overall, the theoretical calculations demonstrate the physical relationship between epoxy coverage and the functional role of the die attach interface. As epoxy coverage decreases, the effective interface area decreases, resulting in a theoretical increase in electrical resistance and thermal resistance, while the effective area available for mechanical load transfer also decreases. Therefore, maintaining sufficient epoxy coverage is important to ensure an adequate die attach interface.

It should be emphasized that the electrical resistance, thermal resistance, and shear load values calculated in this section are theoretical values based on the assumptions that the material properties, BLT, and epoxy distribution are uniform. These values are not direct experimental measurements in this study. The experimental evaluation remains focused on the epoxy coverage condition obtained from the Post Epoxy Inspection (PEI) system and microscope observation. The theoretical calculations are used to explain the physical significance of epoxy coverage and its relationship with the Insufficient Glue defect.

D. Data Collection

The investigation of the Insufficient Glue defect was conducted using several sources of production-related information obtained from the Die Attach process. The objective of this stage was to collect relevant evidence and identify factors that could potentially contribute to the occurrence of the defect under actual manufacturing conditions.

The collected data were screened and evaluated to ensure that only information directly related to Insufficient Glue defects was included in the subsequent root cause analysis. These data sources were selected to provide comprehensive information regarding machine performance, process conditions, defect characteristics, and existing process controls.

Data Source	**Information Obtained**	**Purpose**
Machine Alarm History	Alarm records related to epoxy dispensing abnormalities, including Error 652 (*Insufficient Epoxy Coverage*) and Error 280 (*Epoxy Size Too Small*).	Identify machine conditions associated with Insufficient Glue defects.
Visual Inspection Records	Defect occurrence and epoxy coverage condition.	Verify the characteristics and occurrence of Insufficient Glue defects.
Process Observation	Actual operating conditions during the Die Attach process, including machine operation, adhesive dispensing behavior, and material handling practices.	Identify abnormal process conditions that may contribute to the defect.
Engineering	Technical information	Support the

Discussion	regarding machine behavior, process control, and previous troubleshooting activities.	identification and validation of potential root causes.

Tabel III. Sources of Data for Insufficient Glue Investigation

As part of the investigation, machine alarm history records from the DAG 142 Die Attach machine were reviewed. To ensure the relevance of the analysis, only alarms directly associated with epoxy dispensing quality were selected. Two alarm types were identified as having a direct relationship with Insufficient Glue defects, namely Error 652 (Insufficient Epoxy Coverage) and Error 280 (Epoxy Size Too Small). Error 652 indicates insufficient epoxy coverage during the dispensing process, while Error 280 indicates that the detected epoxy size is below the specified requirement.

Error Code	Alarm Description	Total Occurrence
652	Insufficient Epoxy Coverage	20
280	Epoxy Size Too Small	115

Tabel IV. Dispensing-Related Alarm Records Used in the Investigation

As shown in Table II, Error 652 and Error 280 were selected because they are directly associated with epoxy dispensing quality. During the observation period, Error 652 occurred 20 times, while Error 280 occurred 115 times. The significantly higher occurrence of Error 280 indicates recurring abnormalities in epoxy dispensing performance and supports the selection of these alarms as the primary indicators for investigating Insufficient Glue defects.

In addition to alarm history analysis, direct observations were conducted during production activities to evaluate machine operating conditions, adhesive dispensing behavior, nozzle condition, material handling practices, and operator activities. These observations were performed to identify any abnormal conditions that could influence dispensing performance and product quality.

Visual inspection records were also reviewed to verify defect characteristics and confirm the occurrence of Insufficient Glue conditions. Furthermore, discussions with process engineers and production personnel were conducted to obtain technical insights regarding machine behavior, process control methods, and known issues related to epoxy dispensing performance

The information collected from alarm history records, process observations, visual inspections, and engineering assessments was subsequently organized and used as input data for the Fishbone Diagram analysis. This investigation stage served as the foundation for identifying and evaluating potential root causes associated with the occurrence of Insufficient Glue defects in the Die Attach process **before proceeding to root cause verification and corrective action implementation.**

E. Fishbone Diagram Analysis

Following the data collection stage, a Fishbone Diagram (Cause-and-Effect Diagram) was employed to systematically identify the potential factors contributing to the occurrence of Insufficient Glue defects in the Die Attach process. The Fishbone Diagram was selected because it provides a structured approach for analyzing complex manufacturing problems by categorizing possible causes into logical groups, thereby facilitating a comprehensive root cause investigation.[7]

The Fishbone Diagram was developed using information obtained from the previous investigation stage, including machine alarm history records, process observations, visual inspection results, engineering discussions, and relevant technical references. These sources were used to ensure that the identified potential causes were based on actual production conditions rather than assumptions.

To organize the analysis, the potential causes were classified into six categories based on the 6M approach: **Machine, Method, Material, Measurement, Manpower, and Environment**. Each category represents a group of factors that may influence epoxy dispensing performance and consequently contribute to the occurrence of Insufficient Glue defects. The identified potential causes were generated through technical evaluation of the collected evidence and engineering knowledge of the Die Attach process.[8]

It should be noted that the Fishbone Diagram represents **potential** causes only and does not directly indicate the actual root cause of the defect. Therefore, each identified cause was subsequently evaluated by reviewing the effectiveness of existing process controls and conducting technical verification. This evaluation process was performed to eliminate non-contributing factors and determine the dominant root causes and provide the basis for implementing appropriate corrective actions.

F. Evaluation and Elimination of Potential Root Causes

After identifying the potential causes of the Insufficient Glue defect through the Fishbone Diagram, each hypothesis was evaluated using a structured elimination process. The purpose of this evaluation was to systematically assess whether each identified factor required further investigation during the research. This approach helps narrow down the number of potential causes by reviewing the effectiveness of existing production controls and engineering practices before proceeding to the implementation stage.

The evaluation process was carried out by reviewing the current production control system, engineering standards, machine functions, preventive maintenance activities, and standard operating procedures (SOPs). Each potential cause was assessed based on the availability and effectiveness of the existing control mechanism. Factors that were considered adequately controlled or continuously monitored by the manufacturing process were excluded from further investigation. In contrast, potential causes with insufficient control or without an effective verification mechanism were retained for subsequent analysis and validation.

Following the evaluation process, the remaining hypotheses were not immediately considered as confirmed root causes. Instead, they were selected as candidates for further investigation through implementation, parameter adjustment, and verification activities. This staged evaluation ensures that the subsequent analysis focuses only on the most relevant potential causes while maintaining a systematic and objective problem-solving approach.

The evaluation and elimination process presented in this study serves as a screening method before conducting the implementation stage. The hypotheses retained after this evaluation were further investigated through the glue verification procedure and parameter optimization described in the following sections.

IV. RESULT AND DISCUSSION

Based on the production alarm analysis and visual inspection results, the Insufficient Glue defect was confirmed as a recurring process issue requiring further investigation. Therefore, a systematic root cause analysis was conducted using the Fishbone Diagram to identify the factors contributing to the occurrence of the defect.

A. Root Cause Analysis

Following the identification of the Insufficient Glue defect, a systematic root cause investigation was conducted using the Fishbone Diagram (Cause-and-Effect Diagram). This method was selected because it enables potential causes to be classified into six categories, namely Machine, Method, Material, Measurement, Manpower, and Environment (6M). The purpose of this analysis was to ensure that all possible contributing factors were identified before determining the dominant root cause.

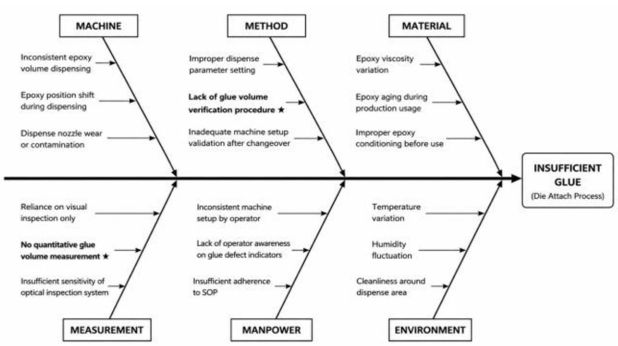


Figure 5. Fishbone Diagram for Insufficient Glue Defect Analysis

As illustrated in Figure 5, several potential causes were identified across the six categories. Machine-related factors included inconsistent epoxy dispensing and nozzle contamination. Method-related factors focused on the absence of glue coverage verification and inadequate setup validation. Material-related factors involved epoxy viscosity and conditioning, while Measurement considered the limitations of visual inspection. Operator-related and environmental factors were also evaluated to ensure a comprehensive investigation.[9]

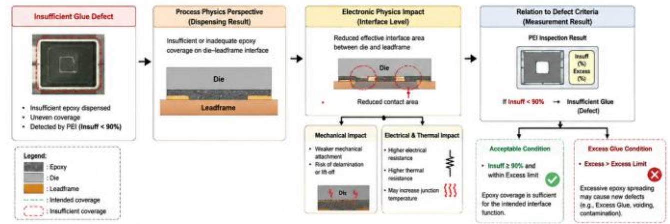


Figure 6. Illustration of insufficient glue defect from process physics and electronic physics perspective and its relation to inspection criteria.

In the die attach process, epoxy functions as an adhesive interface between the semiconductor die and the leadframe. Therefore, an Insufficient Glue defect is not only a dispensing or visual inspection issue, but also represents a reduction in the effective epoxy interface area between the die and leadframe. Insufficient epoxy coverage can affect the integrity of the die–leadframe interface, particularly in terms of mechanical bonding and the continuity of the interface required for electrical and thermal transfer. Consequently, factors that reduce epoxy coverage must be considered in relation to the physical function of the adhesive interface in semiconductor packaging. In this study, the electronic-manufacturing aspect is addressed by evaluating epoxy coverage as the measurable process characteristic used to verify the die attach interface.

Categories	Hypothesis	Current Control	Potential Root Cause (Y/N)	Verification Result
Machine	Inconsistent epoxy volume dispensing	Dispense parameter setting and alarm for epoxy size	N	Existing machine control and alarm are effective
Machine	Epoxy position shift during dispensing	Vision alignment check and position alarm	N	Position-related abnormalities are detected
Machine	Dispense nozzle wear or contamination	Periodic nozzle cleaning and replacement are defined in preventive maintenance checklist	N	Existing preventive maintenance controls are considered sufficient to detect nozzle degradation
Method	Improper dispense parameter setting	Standard parameter setting guideline	N	Parameters are defined and controlled
Method	**Lack of glue Coverage verification procedure**	**No glue coverage measurement or verification after setup**	**Y**	**No mechanism to confirm actual dispensed glue coverage**
Method	Inadequate machine setup validation after changeover	Setup checklist and first article inspection	N	Validation process exists
Material	Epoxy viscosity variation	Incoming material specification	N	Material quality is controlled

		and supplier control		by specification
Material	Epoxy aging during production usage	Defined epoxy usage time limit	N	Aging is controlled by usage time rule
Material	Improper epoxy conditioning before use	Conditioning instruction in material SOP	N	Conditioning process is defined
Measurement	Reliance on visual inspection only	Operator visual inspection standard	N	Visual inspection is supported by alarm system
Measurement	**No quantitative glue coverage measurement**	**Glue condition is evaluated based on visual inspection only**	**Y**	**Actual glue coverage cannot be confirmed numerically, increasing risk of insufficient glue**
Measurement	Insufficient sensitivity of optical inspection system	Machine vision inspection	N	Optical inspection is in place
Manpower	Inconsistent machine setup by operator	Certified operator and WI	N	Operator competency is controlled
Manpower	Lack of operator awareness on glue defect indicators	Training and defect reference guide	N	Awareness control exists
Manpower	Insufficient adherence to SOP	Regular audit and supervision	N	Compliance is monitored
Environment	Temperature variation	Cleanroom temperature control system	N	Environment is monitored
Environment	Humidity fluctuation	Humidity monitoring system	N	Humidity is controlled
Environment	Cleanliness around dispense area	Cleanroom protocol	N	Cleanliness is maintained

Tabel V. Evaluation and Elimination of Potential Root Causes

Following the evaluation process presented in Table III, only two potential causes remained and were identified as the dominant root causes requiring corrective action implementation. The first was the **lack of a glue coverage procedure after machine setup**, where production could proceed without confirming whether the actual dispensed epoxy met the required coverage specification. The second was the **absence of quantitative glue coverage measurement**, as the existing inspection process primarily relied on visual evaluation and machine inspection results without a dedicated verification step to validate the actual epoxy coverage before production release.

The selection of glue coverage as the verification characteristic is related to the function of the epoxy interface in the die attach process. The epoxy must form sufficient and continuous contact between the die and leadframe to provide the intended bonding interface. When the coverage is insufficient, the effective interface area is reduced, which may compromise mechanical attachment and the continuity of the paths for electrical conduction and heat transfer through the package interface. Therefore, quantitative glue coverage verification provides a measurable process indicator for evaluating whether the dispensing process has produced an adequate die attach interface before production release.

~ **Lack of Glue Coverage Verification Procedure**

To support the first identified root cause, the existing AD8312+ machine setup procedure was reviewed based on the standard setup manual and direct observation during machine setup activities. The setup procedure includes device recipe selection, wafer PR teaching, epoxy pad PR setup, dispense alignment, dispense contact level adjustment, post epoxy inspection configuration, bond PR verification, bond position teaching, and bond contact level adjustment before production starts. However, no dedicated glue verification step is performed to verify the actual epoxy coverage immediately after machine setup. Consequently, production may begin without confirming whether the dispensed epoxy satisfies the required coverage specification. This condition increases the possibility that Insufficient Glue defects are only detected after production has started.

From an electronic packaging perspective, the absence of glue verification before production release may allow an insufficient epoxy interface to enter the production process without confirmation of its physical condition. Since the epoxy forms the interface between the semiconductor die and leadframe, insufficient coverage can reduce the effective bonding area and interrupt the continuity of the interface. This condition may affect the mechanical integrity of the die attachment and may also influence the thermal and electrical transfer paths within the package. Therefore, verification of epoxy coverage before production release is important to ensure that the die attach process produces an adequate interface for the intended packaging function.

Figure 7. Machine Setup Procedure Showing The Absence of a Dedicated Glue Verification Step Before Production Release

~ **No Quantitative Glue Coverage Measurement**

The second identified root cause was supported through observation of the epoxy inspection method used during machine setup. The verification process relies on microscope observation and machine output inspection to determine whether the epoxy coverage is acceptable. Although these inspection methods can identify abnormal epoxy coverage, no numerical measurement of the actual epoxy area is recorded before machine release. As a result, the acceptance decision depends primarily on visual inspection and machine judgement rather than quantitative verification of the dispensed epoxy area.

Quantitative epoxy coverage is important because the adhesive interface determines the effective contact area between the semiconductor die and the leadframe. A reduction in the covered area represents a reduction in the effective interface through which mechanical bonding is established and through which electrical and thermal transfer can occur. Therefore, visual inspection alone may confirm the presence of epoxy but does not provide a numerical indication of how closely the actual coverage approaches the required acceptance limit. Quantifying the epoxy coverage provides an objective process characteristic that can be related directly to the acceptance criterion of the die attach process.

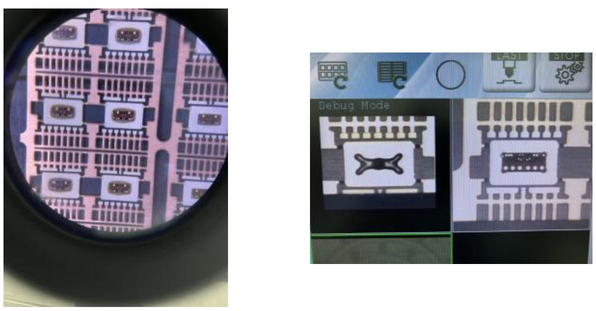


Figure 8. Existing epoxy verification method using microscope observation and machine output inspection without quantitative glue area measurement.

Based on the supporting evidence presented in Figures 6 and 7, both identified root causes were confirmed and subsequently selected as the basis for developing the corrective actions described in the following section.

B. Corrective Action

~ **Lack of Glue Coverage Verification Procedure**

The first dominant root cause identified in this study was the absence of a standardized glue verification procedure following machine setup. Under the existing practice, production could proceed immediately after setup without confirming whether the dispensed epoxy satisfied the required acceptance criteria. Consequently, Insufficient Glue defects could only be detected after production had already started.

To address this issue, a standardized glue verification procedure was introduced before machine release. The proposed procedure requires Engineering Technicians to verify the epoxy dispensing condition immediately after machine setup using microscope observation and the Post Epoxy Inspection (PEI) system. When the inspection result does not satisfy the predefined acceptance criteria, parameter adjustment is performed before production is allowed to continue. This additional verification step ensures that epoxy dispensing quality is confirmed prior to mass production, thereby reducing the possibility of recurring Insufficient Glue defects.

In the die attach process, the Target Area Size provides a process reference for controlling the intended epoxy coverage evaluated by the Post Epoxy Inspection system. Changes in this parameter affect the target dispensing condition and consequently influence the area over which the epoxy is distributed on the die–leadframe interface. An insufficient target area may result in inadequate adhesive coverage, leaving part of the interface without sufficient epoxy, whereas an excessively large target area may promote excessive epoxy spreading and lead to an Excess Glue condition. Therefore, Target Area Size optimization is used in this study to obtain an epoxy coverage condition that satisfies the acceptance criteria while maintaining an appropriate adhesive interface for the die attach process.

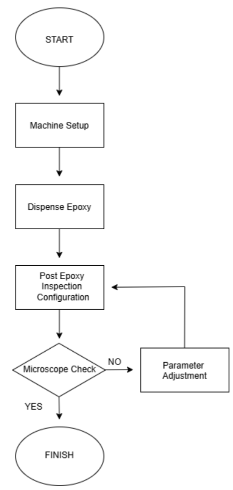


Figure 9. Development of Glue Verification Procedure

~

~ **No Quantitative Glue Coverage Measurement**

The second root cause identified was the absence of quantitative verification of epoxy coverage during machine setup. Existing verification relied mainly on visual inspection and machine judgment without numerical confirmation of the dispensed epoxy coverage.

To address this issue, a quantitative reference for epoxy coverage verification was introduced by utilizing the Target Area Size parameter together with microscope observation. This approach provides Engineering Technicians with a measurable reference for evaluating epoxy coverage before production release.

The proposed corrective action therefore combines parameter-based control with physical verification of the epoxy interface, providing both a quantitative process reference and visual confirmation of the resulting coverage condition before production release.

C. Implementation of Corrective Action

During the implementation stage, the improvement was carried out in collaboration with the Engineering Technician team on Die Attach Machine DAG142. Based on the existing engineering practice, parameter adjustment was performed sequentially to obtain acceptable epoxy coverage. The adjustment sequence followed the standard engineering troubleshooting practice applied during machine setup to ensure that each process parameter was evaluated systematically before modifying the inspection parameters. The adjustment sequence began with verification of the dispense teaching position and dispensing pressure. If the epoxy coverage remained unsatisfactory, the Z Position parameter was adjusted manually within the operating range of approximately 75 µm to 100 µm. After tool replacement, all dispensing parameters were normally reset to their minimum values; therefore, additional parameter verification was required before production release.[7]

From a process-physics perspective, the parameter adjustment sequence was intended to control the amount and distribution of epoxy at the die–leadframe interface. Dispensing pressure influences the amount of epoxy delivered, while the bond level influences the interaction between the dispensing and bonding conditions that determine epoxy spreading. These parameters therefore affect the resulting adhesive coverage observed during Post Epoxy Inspection. In this study, the parameters were evaluated sequentially to identify the parameter that could correct the Insufficient Glue condition without introducing excessive epoxy coverage.

The relationship between the dispensing parameter and the electronic packaging function is established through the resulting epoxy interface condition. Changes in the Target Area Size affect the intended epoxy coverage, while the coverage determines the effective area of the die–leadframe interface. A sufficient and continuous interface provides the physical condition required for the conductive epoxy to perform its intended mechanical attachment and to maintain the material path associated with electrical conduction and heat transfer. Therefore, in this study, the relationship between the glue parameter and the electronic packaging function is evaluated through the measurable epoxy coverage rather than through direct electrical or thermal performance measurement.

The selection of the Target Area Size adjustment interval was based on the engineering troubleshooting practice applied by the Engineering Technician team during the machine setup and parameter optimization process. The Target Area Size was adjusted incrementally so that the response of epoxy coverage could be evaluated at each parameter level while the other dispensing parameters were maintained at their standard values. In this study, the adjustment was performed from the initial Learnt Area Size of 1.914 mm² to 2.000 mm², 2.100 mm², and 2.200 mm². The 0.100 mm² interval was used as an engineering trial interval based on the practical adjustment method applied during troubleshooting, and was not considered a universal specification or a requirement established by the literature. The effect of each adjustment was subsequently evaluated using the Insuff and Excess values generated by the Post Epoxy Inspection system.

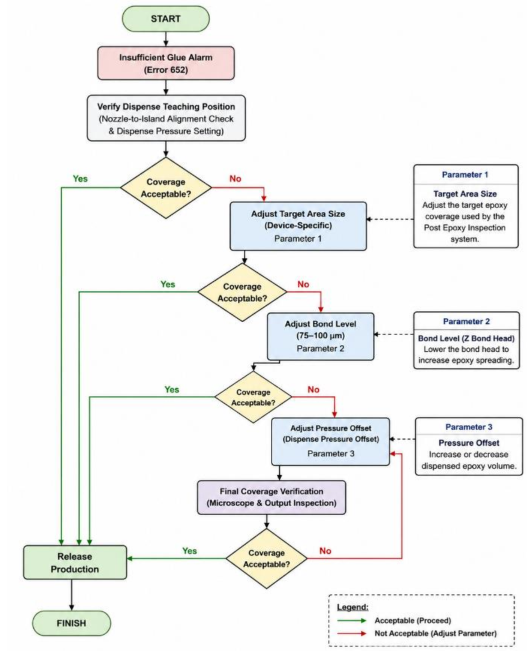


Figure 10. Engineering Troubleshooting and Parameter Adjustment Procedure for Insufficient Glue

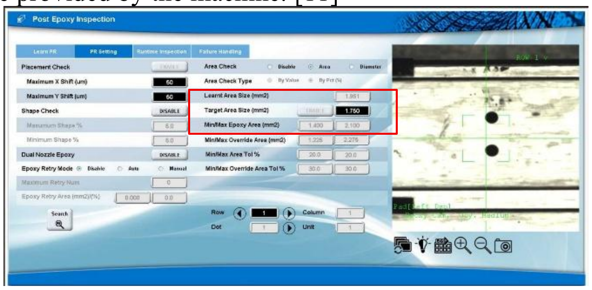
Several parameter adjustment trials were conducted during the implementation stage to obtain an epoxy coverage that satisfied the inspection specification.

Parameter	Default / Range	Adjustment Purpose	Adjustment Condition
Target Area Size	Device dependent	Adjust the target epoxy coverage used by the Post Epoxy Inspection system	First parameter adjusted when Insufficient Glue occurs
Bond Level (Z Bond Head)	75–100 µm	Lower the bond head to increase epoxy spreading	Adjusted if Target Area Size optimization is insufficient
Pressure Offset	Default pressure = 21.0 with adjustable offset	Increase or decrease dispensed epoxy volume	Adjusted only if Insufficient Glue still occurs after Bond Level optimization

Tabel VI. Adjustable Parameters Used During Troubleshooting

To obtain an acceptable epoxy coverage, parameter optimization was performed after the machine teaching process. During machine teaching, the system automatically generated the Learnt Area Size together with the allowable minimum and maximum epoxy area limits based on the selected device recipe. These parameters were used as the reference for subsequent optimization.[10]

In this study, the Bond Level and Pressure Offset parameters were maintained at their standard values because the initial machine teaching had already generated appropriate settings. Therefore, the optimization focused solely on adjusting the Target Area Size parameter within the allowable epoxy area range provided by the machine. [11]



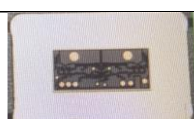
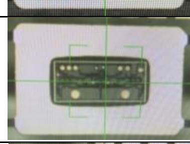
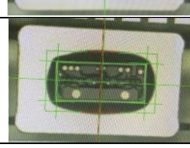
BEFORE

AFTER

Figure 11. Target Area Size Optimization After Machine Teaching

Figure 11 illustrates the Post Epoxy Inspection parameter generated automatically after the machine teaching process. The machine produced a Learnt Area Size of 1.914 mm² together with the allowable epoxy area range of 1.680 mm² to 2.730 mm². These values served as the engineering reference during the Target Area Size optimization process. The Bond Level and Pressure Offset remained at the standard values generated during machine teaching (**Bond Level = 90** and **Pressure Offset = 21.0**) because no abnormalities related to these parameters were observed during setup.[12]

D. Verification and Evaluation of Parameter Optimization

Trial	Learnt Area	Target Area	Insuff Value	Inspection Result	Status
Initial	1.914	1.914	64.3		NG
Trial 1	1.914	2.000	83.2		NG
Trial 2	1.914	2.100	100.0		OK
Trial 3	1.914	2.200	100.0		NG

Tabel VII. Parameter optimization trials during corrective action implementation

During the optimization process, each Target Area Size adjustment was validated through an actual production trial rather than a software simulation. For each Target Area Size, two consecutive production columns (24 die units) were processed before the parameter was adjusted to the next trial value. The resulting epoxy coverage was then evaluated using the Post Epoxy Inspection (PEI) system and microscope observation. If the inspection result still indicated an Insufficient Glue defect, the Target Area Size was increased incrementally while maintaining the Bond Level and Pressure Offset generated during the machine teaching process. This iterative procedure was repeated until all inspected units within the production column satisfied the acceptance criteria. The optimization process continued until the inspection results satisfied the required epoxy coverage specification without introducing Excess Glue defects. The optimum Target Area Size was obtained at **2.100 mm²**, whereas a further increase to **2.200 mm²** resulted in excessive epoxy coverage and was therefore rejected.[13]

The trial results also demonstrate the relationship between the dispensing parameter and the physical condition of the epoxy interface. Increasing the Target Area Size from 1.914 mm² to 2.000 mm² increased the Insuff value from 64.3 to 83.2, indicating an improvement in the detected epoxy coverage, although the minimum acceptance criterion of 90% was not yet achieved. At 2.100 mm², the Insuff value reached 100.0, indicating that the epoxy coverage satisfied the required inspection criterion. This condition indicates that the selected dispensing parameter was able to produce a sufficiently continuous epoxy interface over the intended bonding area. In contrast, increasing the Target Area Size further to 2.200 mm² maintained an Insuff value of 100.0 but introduced Excess Glue, indicating that increasing the dispensing target beyond the optimum condition did not provide additional benefit and instead increased the risk of excessive epoxy spreading.

From the electronic packaging perspective, the epoxy coverage obtained at the optimum Target Area Size represents the physical condition of the die attach interface that supports the intended functions of the conductive adhesive. A sufficiently covered interface provides an adequate bonding area between the die and leadframe, while maintaining the continuous material interface required for electrical conduction and heat transfer through the package structure. Therefore, although electrical conductivity, thermal conductivity, and mechanical bonding strength were not directly measured in this study, the epoxy coverage result is used as the measurable process characteristic for verifying the physical condition of the die attach interface.

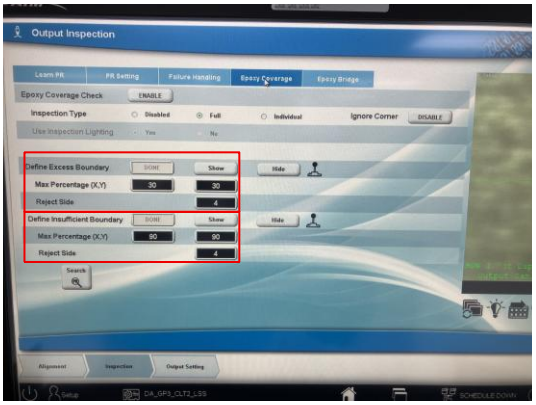


Figure 12. Epoxy Coverage inspection parameters configured in the Die Attach machine

Before evaluating the optimized dispensing parameter, the acceptance criteria used by the Post Epoxy Inspection (PEI) system were verified. The PEI system automatically evaluates epoxy coverage using predefined inspection boundaries configured in the Die Attach machine. During this study, the inspection parameters remained unchanged throughout all optimization trials to ensure consistent evaluation conditions.

For Insufficient Epoxy, the machine acceptance threshold was configured at **90%** coverage. The 90% value used in this study represents the process acceptance criterion for epoxy coverage configured in the PEI system, rather than a direct specification for electrical conductivity, thermal conductivity, or mechanical bonding strength of the epoxy material. These material properties describe the functional requirements of the conductive adhesive interface, while epoxy coverage is the process characteristic experimentally evaluated in this study.

Therefore, any dispensing result with an Insuff value below 90 was automatically classified as Insufficient Glue. Meanwhile, Excess Epoxy was evaluated using the predefined Excess Boundary configured in the PEI system. These inspection criteria were maintained throughout the experiment so that the observed improvements resulted solely from the Target Area Size optimization rather than modifications to the inspection settings.

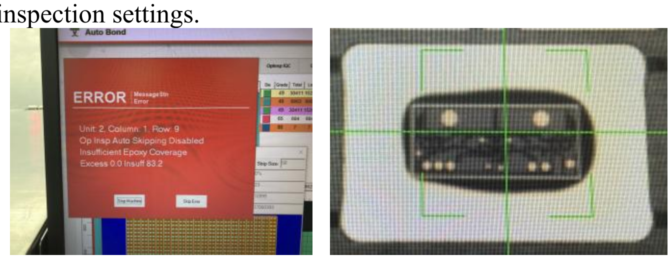


Figure 13. Automatic detection of Insufficient Glue by the Post Epoxy Inspection system

Figure 13 presents an example of the automatic inspection result when the dispensed epoxy failed to satisfy the required coverage specification. The PEI system generated an Insufficient Glue alarm and displayed an Insuff value below the configured acceptance threshold. Based on observations during production, Insuff values of **83.2** consistently produced an Insufficient Glue alarm because they did not satisfy the minimum coverage requirement of **90%**.From the die attach interface perspective, this result indicates that the detected epoxy coverage had not yet reached the minimum area required by the process specification to form an acceptable adhesive interface.

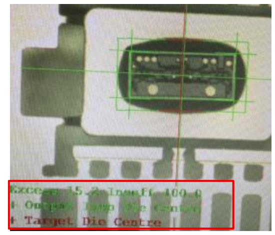


Figure 14. Automatic detection of Insufficient Glue by the Post Epoxy Inspection system

After increasing the Target Area Size, the Insuff value reached **100**, indicating that the epoxy coverage had satisfied the minimum inspection requirement. This confirmed that the optimized parameter successfully eliminated the Insufficient Glue defect. During further parameter adjustment, the PEI system also reported an Excess value, indicating that excessive epoxy spreading began to occur. Consequently, the parameter was not increased further to avoid introducing new dispensing defects. Therefore, the optimum condition was not determined solely from the Insuff value, but from the combined acceptance of sufficient epoxy coverage without introducing excessive epoxy deposition.[14]

Following the PEI evaluation, representative samples were further examined using a microscope to visually verify the epoxy coverage on the die surface. Since the field of view of the microscope was limited, only representative die units are presented in this study. The microscope observation confirmed the PEI inspection results by providing direct visual evidence of the epoxy distribution.

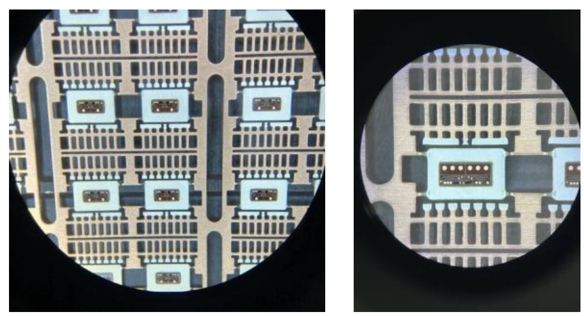


Figure 15. Microscope Verification of Epoxy Coverage

As shown in Figure 15, the optimized Target Area Size produced a more uniform epoxy coverage with continuous adhesive distribution around the die. No obvious insufficient epoxy region was observed on the inspected samples, indicating that the optimized dispensing parameter successfully satisfied the required coverage specification. The microscope observation served as a visual confirmation of the automatic inspection performed by the PEI system.

The continuous epoxy distribution observed around the die also provides physical evidence that the optimized dispensing condition produced a more complete die–leadframe adhesive interface. This interface condition is important in semiconductor packaging because the conductive adhesive simultaneously contributes to die attachment and provides the material interface associated with electrical and thermal transfer between the die and leadframe.

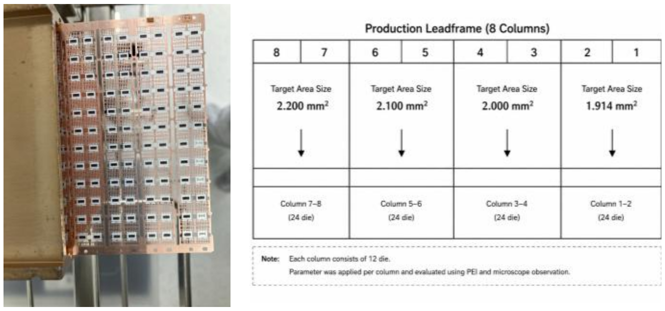


Figure 16. Production leadframe showing the sequential Target Area Size validation performed on different column groups.

Figure 16 shows the production leadframe used during the validation experiment. To minimize process variation, different Target Area Size values were evaluated sequentially within the same leadframe. Each parameter setting was applied to two consecutive production columns consisting of 24 die units before changing to the next Target Area Size. This approach ensured that all parameter comparisons were performed under identical production conditions. A total of 96 die units were evaluated during the optimization process. Each Target Area Size was applied to two production columns consisting of 24 die units before proceeding to the next parameter level.

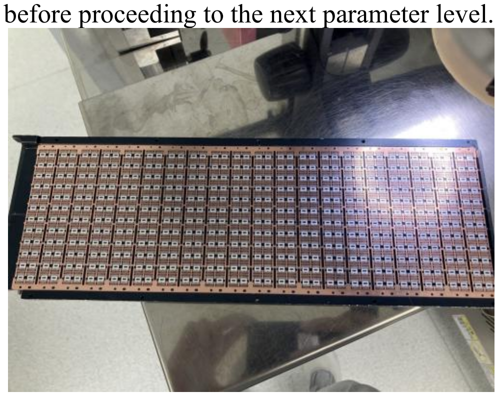


Figure 17. Production leadframe processed using the optimized Target Area Size of 2.100 mm²

After the optimization experiment, the Target Area Size of **2.100 mm²** was successfully applied during production for the same product configuration and process setup. Figure 17 shows a production leadframe manufactured using the optimized parameter, demonstrating stable epoxy coverage under actual production conditions.

It should be noted that the optimized Target Area Size obtained in this study is **specific to the investigated product and process configuration**. In actual manufacturing, the dispensing parameter may require re-teaching or readjustment whenever a change in device type, dispensing nozzle, epoxy material, or bonding tool occurs, since these factors influence the epoxy dispensing characteristics.

V. CONCLUSION

The objective of this study was to develop a systematic glue verification procedure for investigating and handling **Insufficient Glue** defects during the die attach process. Based on the alarm analysis and root cause investigation using the Fishbone Diagram, it was identified that the absence of a standardized glue verification procedure during machine setup contributed to the occurrence of dispensing abnormalities.

Based on the identified root cause, a glue verification procedure was developed by adopting the engineering troubleshooting sequence used during machine setup. The proposed procedure consists of sequential verification of dispense teaching position, dispensing pressure, Z Position, Target Area Size, and dispense pattern before performing the final inspection. This systematic approach provides a structured guideline for Engineering Technicians during parameter adjustment.

The proposed procedure was implemented on Die Attach Machine DAG142 for the L8406J device. During implementation, several parameter adjustment trials were performed by gradually increasing the Target Area Size from the default setting until the optimum value of 2.100 mm² was obtained. The implementation was subsequently verified using microscope inspection and the machine output inspection system. Both verification methods confirmed that the optimized parameter produced acceptable epoxy coverage in accordance with the production acceptance criteria. From an electronic manufacturing perspective, the optimization improved the physical condition of the die attach adhesive interface by achieving sufficient and controlled epoxy coverage, which is an important process condition for maintaining the mechanical attachment and the intended electrical and thermal interface functions of the semiconductor package.

Overall, the developed glue verification procedure provides a practical and systematic approach for supporting parameter adjustment during machine setup. The proposed procedure can assist Engineering Technicians in performing parameter verification in a structured manner before machine release, thereby improving the consistency of epoxy dispensing quality.

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