EFFECT OF HEAT DISTRIBUTION AND VIBRATION ON WIDER LEAD FRAME

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ABSTRACT

Adoption of more electronic components in end products, the semiconductor industry is facing a challenge era that requires price management to achieve efficiency, high productivity and excellence with each of the diverse customers. One of the strategies is to enhance the wider of lead frame size for cost down reduction related on material and increase the productivity. However there are two main challenges of wider lead frame implementation which is heat distribution not even and vibration issue that will cause bonding performance no good. Heat distribution uneven is causing warpage due to heating principle at machine. High density unit per lead frame may contribute to warpage and it cannot be avoid. This issue can be improving by design consideration of dimple installation in order to release the material stress after applied heat. For vibration concern, upward floating lead on widen lead frame give potential of finger lead bouncing during bonding process, make the second bond ability become weak. As for future improvement, some modification on die-set stamping required to flatten the finger inner lead and reduce their vibration.

KESAN PENYEBARAN HABA DAN GETARAN PADA LEAD FRAME BERSAIZ BESAR

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ABSTRAK

Industri semikonduktor menghadapi era mencabar yang memerlukan pencapaian harga yang efisiensi dan produktiviti tinggi. Salah satu strategi adalah dengan menambah saiz of bingkai plumbum yang dapat meningkatkan quantity unit and menambah productiviti. Namun terdapat dua cabaran utama dalam melaksanakan project ini, ia adalah penyebaran haba yang tak seimbang pada bingkai plumbum dan masalah getaran yang akan mengakibatkan quality yang tidak memuaskan. Penyebaran haba yang tidak sekata menyebabkan bingkai plumbum melengkung. Semakin tinggi kepadatan unit pada suatu bingkai plumbum, semakin tinggi kadar lengkungan yang terhasil. Masalah ini dapat diperbaiki dengan pertimbangan pada desain untuk mengurangkan tegangan material setelah haba dibekalkan. Untuk masalah getaran, apabila kaki bingkai plumbum tidak mendatar sepenuhnya, ia menyebabkan kaki bingkai plumbum melantun apabila ditekan semasa bonding proses. Akibatnya, pembentukan ikatan pada bahagian itu menjadi lemah. Untuk perbaikan isu ini pasa masa depan, modifikasi pada dieset diperlukan untuk meratakan jari bingkai plumbum dan mengurangi getarannya.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

IC : Integrated Circuit

GWP : Gross World Product

SIA : Semiconductor Industry Association

QFP : Quad Flat Package

LF : Lead frame

CZ : Cool zone

HZ : Hot zone

D.I. : De-ionized

CHAPTER 1: INTRODUCTION

1.1 Semiconductor Manufacturing General Overview

The semiconductor component is a tiny electronic device that comprised of billions components to store, move and process data. It is a rapidly expanding sector due to rise of demand for consumer electronic product (GmbH, 2019). Electronic component plays important role and contribute to various advanced technologies that have changed the world that we live in today. Semiconductor electronic industry is the largest industry in the world over one trillion dollar since 1998. The sales volume of electronic industry will reach three trillion dollar and constitute about 10% of GWP (Gross World Product) in 2020. Based on Semiconductor Industry Association (SIA) report on 2018 (Hitachi, 2018), China continued be the strongest region and showed exception annual growth in its three-month average market up to $14.35 billion, up 26.3 percent (Clarke, 2018). The Asia-Pacific region excluding China and Japan are the next largest with three-month-average sales of $10.42 billion but annual growth of only 2.4 percent (Hitachi, 2018).

The semiconductor market has become more competitive and innovative. The industry requires price management to achieve efficiency, high productivity (Jianhua, 2008) and excellence with each of the diverse customers. One of the strategies is to enhance the wider lead frame size for cost down reduction related on material and increase their productivity.

1.2 Lead Frame

Lead frames are a thin and long strip metal structure that used in almost all semiconductor packages. The die inside the package is attached on the island of the lead frame, and then bond wires attach the die pads to the leads during package assembly process. Lead frame represent critical component of semiconductor package. Each company has their package structures and patents based on their design rules and application.

Function of lead frame as per below (Breedis, 2001)

a) To permit electrical contact between the devices on the chip and the microscopic world.

b) To disperse excessive heat. While in operation, many electronic devices generate significant quantities of heat which must be dissipated from chip

c) To protect fragile electronic connection on the chip from chemical degradation and contamination.

d) To provide mechanical support so that the small and fragile chip may be handled

e) To provide an adequate electrical interface such that the performance of IC which itself is not significantly degraded by the package design.

These are standard requirement for lead frame to supplier (Mahulikar, 2002). They are

a) High strength to resist thermal cycle damage

b) High thermal conductivity for heat dissipation and low electric resistance to enhance their performance

c) Good surface properties that contribute to bonding, molding and reliability performance.

Semiconductor industry evolves from normal density of high density. Some company customizes the design of wider lead frame by increase the row or column of unit cavity. By doing this, quantity cavity per lead frame increase, and price lead frame will reduce. At the same time, productivity will be increased as machine stoppages due to material change will be reduced.

1.3 Problem Statement

Main challenge of wider lead frame is distribution of heat transfer and vibration issue.

i) Heat transfer distribution

Heat transfer through lead frames is dependent upon the size of the lead frame. More heats will be lost if through a wider lead frame than through a smaller lead frame of the same composition and thickness. More heats will be lost if through a larger area than through a smaller area with the same insulation characteristics. As such, the rate of heat transfer is proportional direct to the surface area which the heat is being conducted. Impact of this heat loss, die attach is not even and bonding performance not good.

ii) Vibration

More vibrations happens on wider lead frame as lead frame metal structure very thin and the thickness about 0.125 mm. Vibration in bond process might come from bonder machine, handling and transportation to next process. Such vibration may cause bond wire break and wire drop.

1.4 Objective

The objective of this work is to reduce the cost without jeopardizing the product quality and to improve productivity that related on material used in semiconductor component. However, for wider lead frame implementation in semiconductor line, there are lot of challenges need to overcome especially for assembly performance, equipment and process input enhancement. Main obstacles for wider lead frame are heat distribution and vibration. For this work, we only focus to investigate the effect of heat distribution and vibration on wider lead frame.

1.5 Aim

The aim for this work is

a) To evaluate assembly performance on wider lead frame and compare with existing lead frame size as benchmark.
b) To study the heat distribution of wider lead frame using profile temperature
c) To understand the mechanism of failure causing by heat transfer and vibration.
d) To propose the improvement to reduce the problem.

1.6 Scope of study

This work is focus on package QFP(CU) 0707 and QFP(CU) 1010 lead frame in matrix line.

1.7 Structure of the report

This report consists of five chapters starting with Chapter One as the introduction of the project and ended with Chapter Five as the conclusion of the project. The structure of the report is categorized in chapter by chapter.

Chapter One is the introduction that gives brief explanation about the research project. It consists of background of the research, problem statement, objectives, aim , scope of study and structure of the report.

Chapter Two presents a literature review which covers background discussion of the characteristic of lead frame in term of chemical composition and physical properties. In this chapter also discuss about lead frame design and structure, challenge of widens lead frame and product selection as representative for this evaluation.

Chapter Three describes the evaluation plan and the preparation of material, the experimental methods, and procedures used to access the impact of heat distribution and vibration.

Chapter Four presenting the results from this research with the supporting information from various sources. The discussion on differences, further analysis, and determination of potential failure mechanism is carried out.

Chapter Five summarizes the results obtained in this research project and presents the main conclusions and suggest recommendations for future work.

CHAPTER 2: LITERATURE REVIEW

Lead frame is the largest portion of materials cost in semiconductor package (Kiat & Tan, 2010) especially for quad flat package (QFP). Lead frame market demand is increasing and Asia Pacific regions especially in Japan, China and Korea contribute a great volume in the lead frame industry; followed by North America. Mostly lead frame made by SH Materials, Mitsui High-Tech, SDI, Shinko, ASM Assemble Materials Limited, Samsung, POSSEHL and I-Chiun (El, 2019). The design is customized and pattern by each industry.

2.1 Characteristic of Lead frame

For Cu strips of semiconductor lead frame, oxygen free Cu based alloys is designed for discrete, transistor and IC's devices. It is high strength and high electrical conductivity alloys for high pin count device. Below Figure 2.1 is shown relations between tensile strength and electrical conductivity for the lead frame raw material (Hitachi, 2019). HCL-305 has low electric conductivity but high strength and it is a used for tiny SOT packages for mini mold transistors in mobile devices application. C151 has high electric conductivity but less strength (Mitsubishi, 2019) and it is used for PLCC packages that equivalent to CDA1510 in TBGA product with high heating and softening resistivity as same as HCL-02Z. The CDA194ESH widely use as lead frames raw material such as Kobe/Mitsubishi/SH Copper supplier. It has high strength stamping properties and applied to IC lead frames and connectors all over the world. With advantages of good plating, etching, stamping properties, higher heat/softening resistance and offers much higher stamping efficiency and it is highly recommended among the customers.

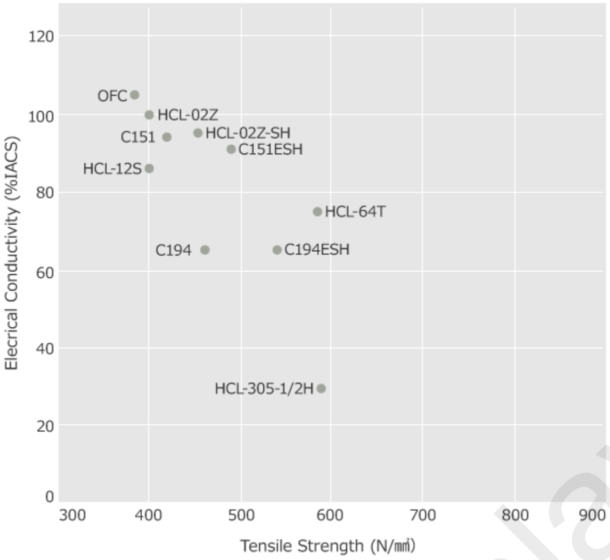


Figure 2.1: Relations of tensile strength and electrical conductivity for lead frame material

2.1.1 Nominal chemical composition

Composition is basic elements need to be considered for high strength, high electrical conductivity and improving their properties. In this study, we use Cu-Ag lead frame. Generally, Fe element can improve the strength and electrical conductivity. However, strength is insufficient, so there are a few problems with the secondary bond-ability properties. Addition of P and Zn element is improved strength. They provide good well-balanced properties. For the reasons outlined above, we used Cu-(Fe, Zn)-P alloy to develop most of Cu-Ag lead frame (Kang & Park, 2007).

Table 2.1: Range of chemical composition for lead frame

Fe	P	Zn	Cu
2.1~2.6	0.015~00.15	0.05~0.20	Bal.

(unit wt%)

2.1.2 Physical properties

Table 2.2: Physical properties for lead frame(Hitachi, 2019)

Item	**Unit**	**Value**
Density at 20 deg	g/cm³	8.91
Modulus of elasticity	kN/mm²	121
Poisson ratio	-	0.33
Electrical Resistivity	μΩm	$2.54X10^{-2}$
Thermal conductivity at 20 deg	W/(m.K)	$2.62X10^{2}$
Coefficient of thermal expansion at 20~300 deg	$10^{-6}/K$	17.7
Specific gravity	g/cm³	8.8
Melting point (Liquid)	^{o}C	1089
Melting point (Solid)	^{o}C	1084

**Reference value only*

2.2 Lead frame design features

One unit cavity lead frame has 3 main components which is lead frame island, finger inner lead frame and suspender as per shown in Figure 2.2. Chip or pellet allocate at island lead frame and connect with finger inner lead frame by using wires. Suspender is used to hold the island center of lead frame.

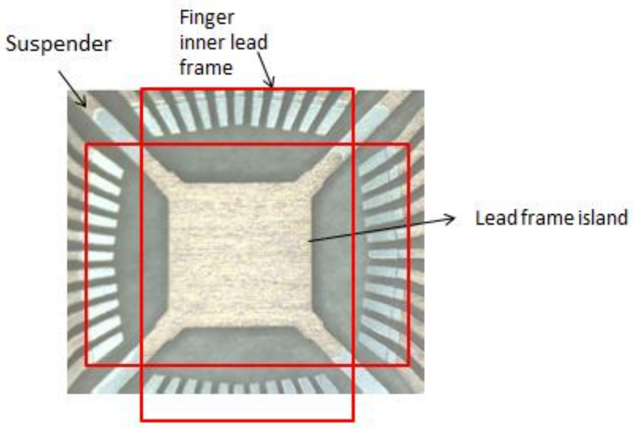


Figure 2.2: Component for one unit cavity lead frame

Illustration for general component on one lead frame is shown in Figure 2.3.

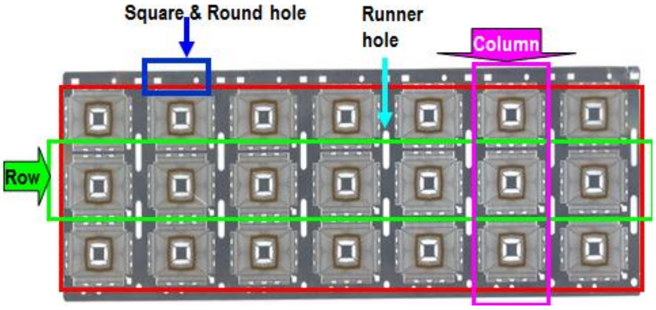


Figure 2.3: General component in one lead frame

In this feasibility study, we survey on the design capability by adding row or column per lead frame. Target lead frame size increase from 72mm x 223.4mm to 80mm x 250mm**.** Target size setting based on existing machine rail dimension and lead frame design rules. Based on this information, maximum unit cavity per lead frame is proposed for widen lead frame shown in Table 2.3 below.

Table 2.3: Proposal of add cavity number of lead frame for QFP (Quad-Flat package)

Pkg	**Item**	**Lead frame width (mm)**	**Column**	**Row**	**Pcs/ LF**	**Result**	**Possibility**
			X	**Y**			
0707	Original	72mm x 223.4mm	12	5	60	Reference	
	Proposal 1	80mm x 250mm	12	6	72	More empty area	
	Proposal 2	80mm x 250mm	13	6	78	More empty area	
	Proposal 3	**80mm x 250mm**	**14**	**6**	**84**	**No problem**	**O (Easy)**
	Proposal 4	80mm x 250mm	15	6	90	No space	X (Not applicable)
1010	Original	72mm x 223.4mm	10	4	40	Reference	
	Proposal 1	80mm x 250mm	10	5	50	More empty area	
	Proposal 2	80mm x 250mm	11	5	55	More empty area	
	Proposal 3	**80mm x 250mm**	**12**	**5**	**60**	**No problem**	**O (Easy)**
	Proposal 4	80mm x 250mm	13	5	65	No space	X (Not applicable)

2.3 Assembly challenge of widen lead frame

The first challenge of widen lead frame is the design challenge (Wyant, 2016). Widen lead frame will be subjected heat distribution caused to more warpage during assembly process compared to lead frame traditionally used. In term of design, as warpage control on the external edge area of the lead frame and supporting structures also need to consider. This is because of the package stress caused by warpage and handling can lead to higher defect formation due to the addition unit per lead frame. Normally, the lead frame is dispensed and heated one unit at a time and then indexed into the place area for die or bond placement. With widen lead frames, the time and placement has become too long. For mounting process, the epoxy forms a dry layer and die attach dry out problems have been encountered. This will cause void, incomplete epoxy with uneven heat profile. This variation will generate issues at the wire bond and molding processes in the form of scrap yield loss. In bonding process, by designing the clamp with a larger area opening, the machine output is maximized, and efficiencies are gained via wide lead frame use. The correct design requires with maximized output results for the tool and heat distribution without impacting bonding wire pull and shear data. Sometimes, indexing and bonding parameters optimization needed.

The second challenge is vibration. Wider and longer lead frame with the same material thickness makes handling the lead frames at each processing step a challenge. Vibration might cause by lead bouncing, transportation, machine vibration and handling (Wyant, 2014). Basically, every machine has vibration sensor to check any abnormality during the process. For quality point of view, a visual operation to check for performance of the process is required. This includes bond line thickness measurements, wire bond loop measurements, and pulls/shears strength. Example wire defect such as B-point cut, D-point cut, lead not stick, wire deformation and weak neck.

2.4 Product Selection

Pertaining to the concern of heat distribution and vibration that causing wire related defect, maximum wire length is the worst criteria and selected as representative for this study. In this work, evaluation is carrying out on package size (0707) and (1010) only.

a) Package QFP (CU) 0707

For QFP (CU) 0707 package, it has 48 pin counts and the targeted lead frame which is PEA48CHT-HB and CEA48LL-HB has maximum wire length is 1.88mm and pellet size is 2.17mm x 2.06mm while their lead frame island is 2.50mm x2.50mm shown in Table 2.4 below.

Table 2.4: Matrix of targeted sample of 0707 package with the max wire length, pellet size and island size information

Lead frame	Wire	Max wire length (mm)	Pellet size (mm)	Island size (mm)	Evaluation	Remarks
PEA48CHT-HB (72mm) to CEA48CLL-HB (80mm)	Au wire (18µm)	1.88	2.17 x 2.06	2.50 x 2.50	√	Max wire length of targeted lead frame

b) Package QFP (CU) 1010

For QFP (CU) 1010 package, it has 44 pin counts. Table 2.5 show the targeted lead frame PKC44CAAT-BB and CKC44CABS-BB combination with their maximum wire length, pellet size and island size information. Maximum wire length is selected as representative for this evaluation.

Table 2.5: Matrix of targeted sample of 1010 package with the maximum wire length, pellet size and island size information

Lead frame	Wire type	Max wire length (mm)	Pellet size (mm)	Island size (mm)	Evaluation	Remarks
PKC44CAAT-BB (72mm) to CKC44CABS-BB (80mm)	Au wire (18µm)	2.03	1.59 x 1.60	2.50 x 2.50	√	Max wire length of targeted lead frame
		1.87	2.02 x 2.02	2.50 x 2.50		
		1.95	1.80 x 1.50	2.50 x 2.50		
		1.98	1.92 x 1.50	2.50 x 2.50		
		2.02	1.70 x 1.54	2.50 x 2.50		

CHAPTER 3: METHODOLOGY

3.1 Evaluation plan

In this study, two size of lead frame which is 72mm x 223.4mm is used as reference and 80mm x 250mm (Widen LF) as evaluation sample have been evaluated and examined as shown in Table 3.1. They are from two packages which is 0707 and 1010. Package naming is based on the length and width unit cavity size which is 0707 (7mmx7mm) and 1010 (10mm x 10mm). The differences between these two packages are the quantity of cavity unit per lead frame and package size. 0707 package have 60pcs unit cavity per 72mm x 223.4mm lead frame and 84pcs unit cavity per 80mm x 250mm (Widen LF) lead frame while 1010 package have 40pcs unit cavity per 72mm x 223.4mm lead frame and 60pcs unit cavity per 80mm x 250mm (Widen LF) lead frame.

Table 3.1: Evaluation plan

Set	Item	Package	Lead frame name	Quantity
1	Reference (72mm)	QFP(CU) 0707	PEA48CHT-HB	3 LFs
	Evaluation (80mm)	QFP(CU) 0707	CEA48CLL-HB	5 LFs
2	Reference (72mm)	QFP(CU) 1010	PKC44CAAT-BB	3 LFs
	Evaluation (80mm)	QFP(CU) 1010	CKC44CABS-BB	5 LFs

3.2 Experimental

3.2.1 Material preparation

For material preparation, flow as per shown in Figure 3.5.

3.2.1.1 Pelletizing

Wafer is mounting on the adhesive sheet, and dicing machine will dice the wafer into pieces (Imamura, 1994). Individual silicon chips (die) are separated from each other on the wafer and get the wafer cut per each line by sawing blade with the D.I (De-ionized) water to prevent any electrostatic issue or contamination. De-ionized water is water that had almost its minerals ions removed such as sodium, iron, copper, calcium, chloride and sulfate. After that, the adhesive sheet needs to expand for wafer in pieces form easily to pick up

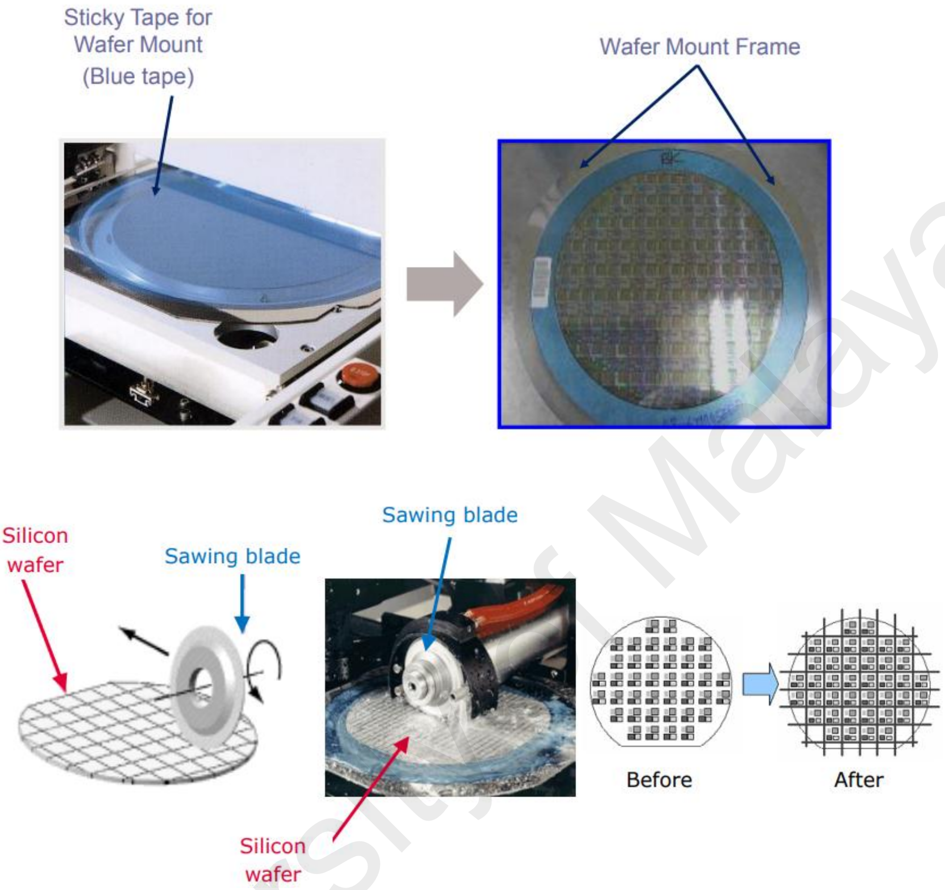


Figure 3.1: Pelletizing process with wafer mount and dicing

3.2.1.2 Mount process

At mounting process, the wafer in pieces form is attached onto the lead frame island sample by using the epoxy adhesive. Epoxy is dispensed in the island of the 72mm x 223.4mm and 80mm x 250mm (Widen LF) lead frame and followed by a pick and place process that removes the wafer in pieces form from the expansion tape wafer and places it over the dispensed epoxy. The dies attach paste cured in order to harden it. Beside that's, it will obtain its optimal mechanical and electrical properties. Checking item as specified in Item 3.2.2 is performed.

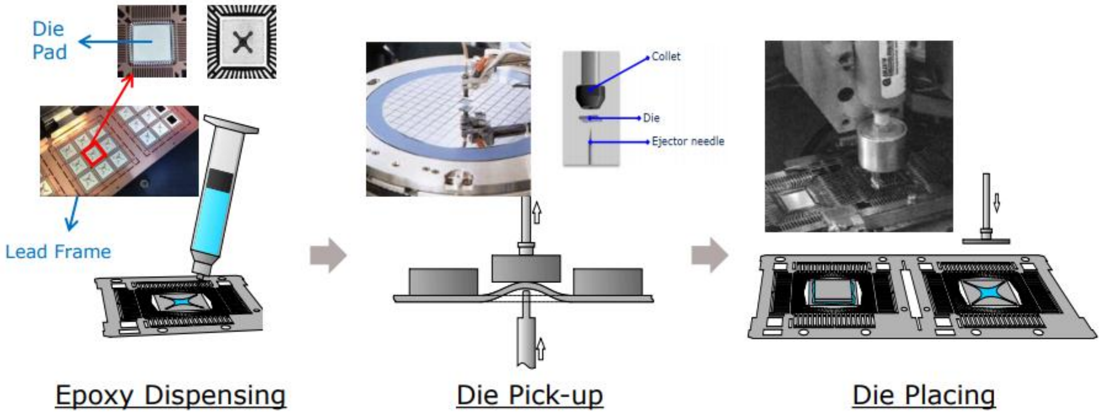


Figure 3.2: Die-attach process

3.2.1.3 Wire-Bond process

This process will connect the attached dies and inner lead frame with gold wires. Before start bond, work holders and heater plate are placed on the lead frame bond area in order supply heat, maximize productivity and simplify job changeovers by allowing locking and positioning with the work already in place. Wire supplied on the MAXUM bonder. Gold ball is first formed by melting the end of the wire using bonding tool that known as capacity through electronic flame-off (EFO). This free-air ball is formed with diameter range from 1.5 to 2.5 times the wire diameter (Fu-liang & Han, 2012). Their size is consistent and brought into contact with bond pad of the inner lead frame. Pressure, heat and ultrasonic forces are applied ball bond itself into its final shape on first bonding. The capillary position and wire are connecting between inner lead frame and bond pad and forming a gradual looping. During this process, pressure and ultrasonic forces are applied to the wire to form the second bonding (stitch bond) at inner lead frame finger. The wire is break in preparation for next wire bonding cycle by clamping the wire and raising the capillary. Checking item as specified in Item 3.2.2 is performed.

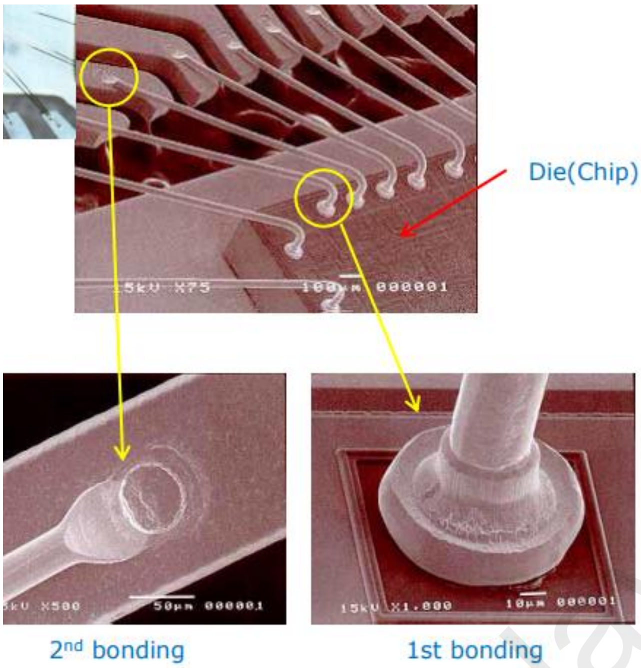


Figure 3.3: First and Second Bonding

3.2.1.4 Sealing process

The purpose of this process is to protect the device mechanically and environmentally from the outside environment like light, heat, corrosion, humidity and dust. Firstly, the bonded sample is put into a mold and epoxy compound is load onto pot. Top and bottom is closed with high amount of clamping force and transfer unit pushes compound up. The compound is applied with high temperature which is around 180 degree Celsius and melting. The melting compound flow into molding areas slowly without bending the thin wires, no void and the top-bottom mold keep closed until the compound completely has been cured. After cured, top-bottom mold is open (Gotro, 2017). The molded products are taken out. After that, gate is break and the resin flash is removed.

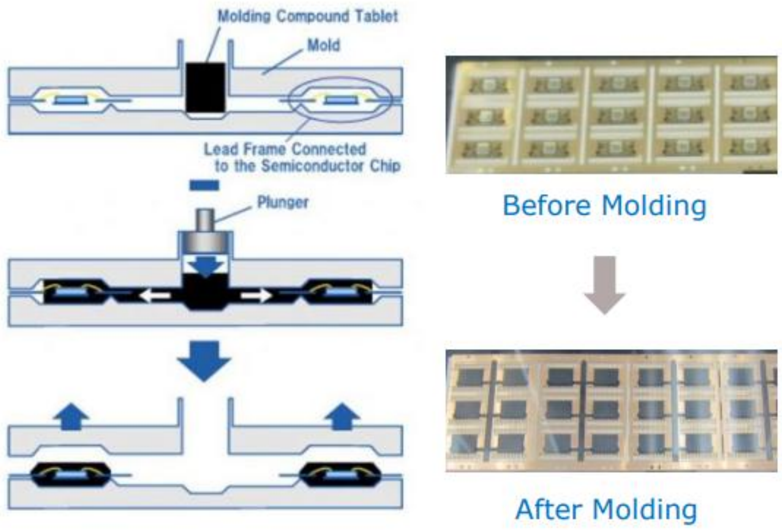


Figure 3.4: Molding mechanism

3.2.1.5 Plating, Cutting and marking

In plating process, molded sample put through a series step involving, rinse, plating, drying and inspection to apply coating pure tin over their lead frame (Tanimoto & Tanaka, 2000). The purpose of this process is for protection of corrosion, abrasion and solders ability improvement. In order to put indication on the cavity unit for traceability, the unit is marked using laser making. The marked sample in lead frame form is cut and lead is formed into correct shape and position. The individual unit is auto-inspecting their lead co-planarity and placed in trays send to next process.

3.2.1.6 Testing

Testing process is to verify the functionality of the device by electrifying test. It can segregate the good device from the reject device (Ripin, 2018).

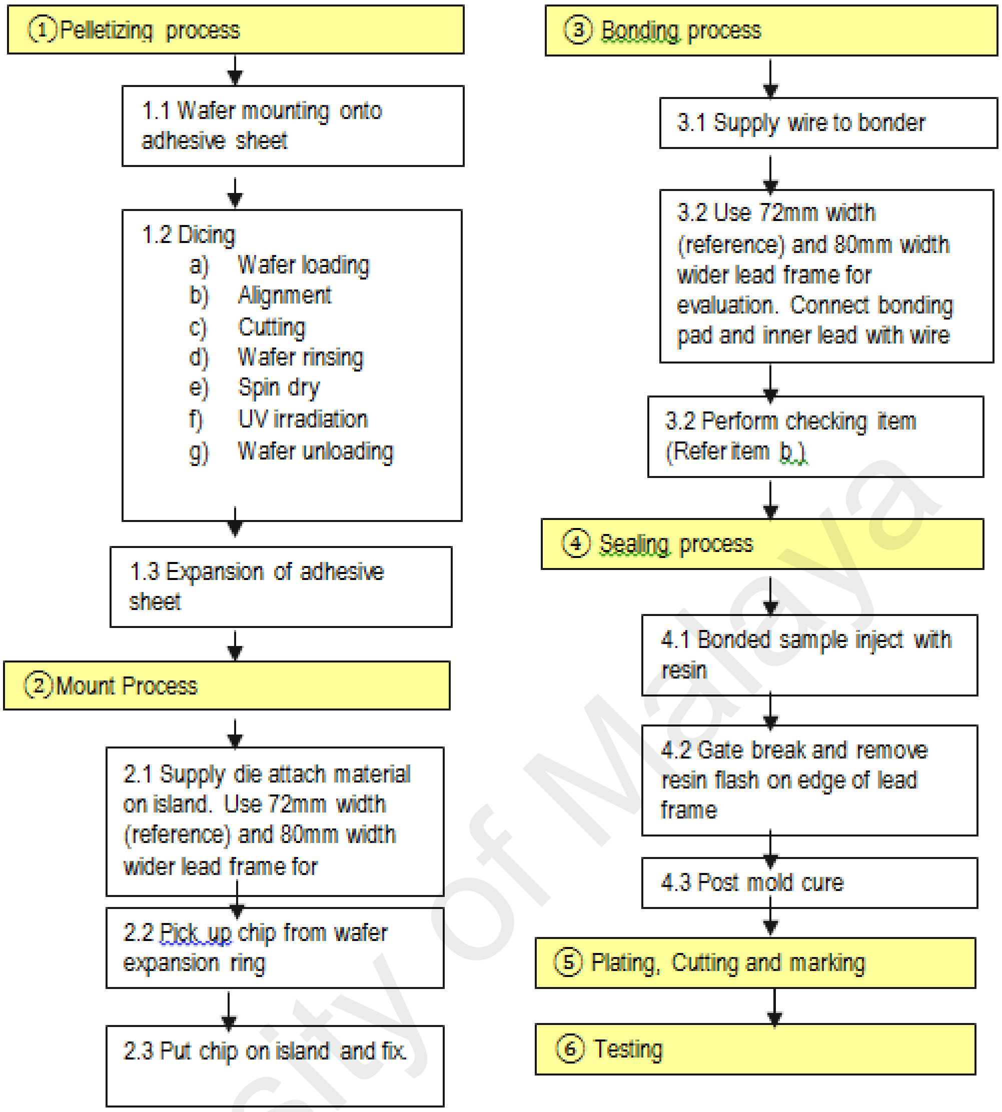


Figure 3.5: Material Preparation Flow

3.2.2 Experimental Check Item

3.2.2.1 Heat distribution check

Temperature profile checked at mounting and bonding process is performed to verify significant different on the temperature for all lead frame position. For mount inline cure, by using thermocouple, temperature at 3 point is measured at unit cavity of First/Middle/End column of lead frame. The temperature reading is taken and comparison graph is plotted (Leonard & Swanson, 2001). For bonding process, temperature for each unit per column of lead frame is measured and temperature reading is compared between 72mm x 223.4mm (reference) and 80mm x 250mm (evaluation of widen LF). Effect of heat treatment and temperature on the growth of inter-metallic compound layer is examined for the bonded sample. IMC percentage is calculated using software. Theoretically, inter-metallic (IMC) growth increases the bonding strength between wire and Al pad (Bernasko, 2012) for mechanical failure reduction (Wulff & Breach, 2006), so wire pull strength (first and second bond) and shear strength check is performed to validate the theory. For wire pull strength test, a small hook is attached to the wire loop and pulled used to measure the strength of the wire bond called as "Pull Test" (MCM-L, 2002). The hook is generally placed at the highest point close to the 1st bond and 2nd bond to measure the strength of the 1st bond or 2nd bond. Below photo is the place hook for pull test measurement. If the hook is placed at the mid span of the wire, then the test will show the average strength of 1st and 2nd bond and this is weakest link of the bond.

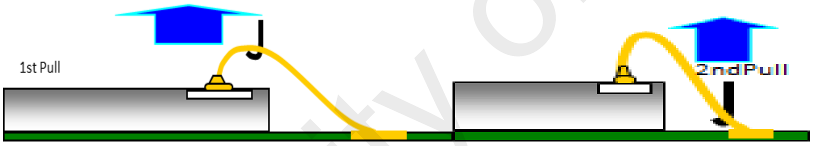


Figure 3.6: Pull test illustration

This pull test is a destructive test and pulls test specification is depends on wire. Min pull test 1.8gf for 18um wire diameter and 2.4gf for 20um wire diameter. This test is good for monitors the quality of the wire bond process. Ball shear test is method for evaluating the quality of a ball bond. A shear tool is aligned adjacent to the ball bond and a force is applied to measure the bond strength. The ball shear is gauged by gram force over the area of the ball formation. Their data reflects the inter-metallic formation and its coverage of the bonds on bond pad (H. Charles, G. Clatterbaugh, 1984). So, a larger ball should have a higher shear strength based on a larger area of inter-metallic formation between the Gold (Au) balls or Copper (Cu) balls with Al bond pad metal on their bond pad.

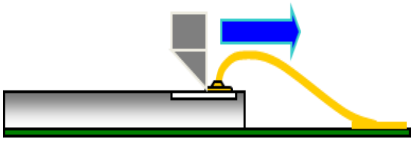


Figure 3.7: Ball shear illustration

Ball size and thickness check is performed to confirm there are no significant different on both sample that might impact to mechanical performance and pull strength reading.

3.2.2.2 Vibration check

At bonding process, vibration sensor is installed at the bonder and the vibration level for each indexing in wave form is captured. Besides that, the visual inspection is performed to detect any appearance of bond defects due to high vibration on finger inner lead frame and second bond that may results to an open or short based on a specified define criteria of wire. Loop height measurement is performed to guarantee device integrity. High loops can result in produce long can causing wire drop due to high vibration of inner lead(Shimada, Onodera, Nonaka, & Ohmi, 1994). At testing process, segregation on the defect is performed and analyzed if any.

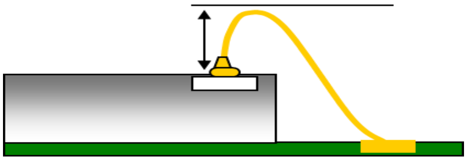


Figure 3.8: Loop height check illustration

Below is the summary of the assembly checking item with their quantity and judgment at mounting, bonding and testing process.

Table 3.2: Assembly Checking item For Mounting process

Check item	Method	Check quantity	Judge
Mount inline cure (Temperature distribution check)	Inline cure program	> 1 LF	Comparable
Mount appearance check	Microscope	100%	Critical defect (0,1)

Table 3.3: Assembly Checking item For Wire Bond process

Check item	Method	Check quantity	Judge
Bonding temperature distribution check	Thermocouple	Full unit in a column X 1 LF	Monitoring
IMC check	SEM and software	3 columns in 1 LF (First/ Middle/End)	IMC > 70%
Bond appearance check	Microscope	100%	Critical defect (0,1)
Bond stitch appearance check	Metallurgical scope	First and last row x 1 LF	(0,1)
1st Pull strength	Auto bond tester	4 balls x 4 sides x 3 rows/IC (48 data)	(0,1)
2nd Pull strength	Auto bond tester		(0,1)
Wire loop height	Metallurgical scope		(0,1)
Ball size	Metallurgical scope		(0,1)
Ball thickness	Metallurgical scope		(0,1)
Ball shear strength	Auto bond tester		(0,1)
Vibration check	Vibration software	100%	Monitoring

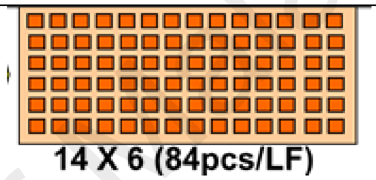
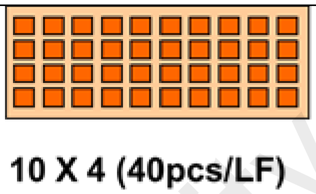
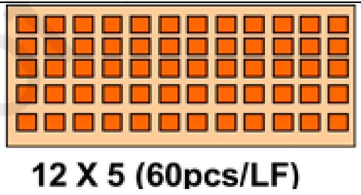
Table 3.4: Assembly Checking item For Testing process

Check item	Method	Check quantity	Judge
Testing yield	Good/Work x100%	100%	> Std yield
Defect analysis	Manual test / x-ray / de-capsulation	Failed unit	Critical defect (0,1)

CHAPTER 4: RESULT AND DISCUSSION

By widen lead frame size, unit density per lead frame is increasing. For QFP(CU) 0707 package, unit cavity per lead frame increase from 60pcs to 84pcs (+40% density) while for QFP(CU) 1010, unit cavity per lead frame increase from 40pcs to 60 pcs (50% density).

Table 4.1: Cavity illustration for reference and evaluation sample

Package	Reference (72mm x 223.4mm)	80mm x 250mm (80mm x 250mm)	Density
0707			+40%
1010			+50%

In this study, the focus is on the effect of heat distribution and vibration for two sizes of lead frame configurations.

4.1 Effect of heat distribution on lead frame size

4.1.1 Mount inline cure temperature distribution

At the mounting process, lead frame sample is moving from zone 1 to zone 8 and temperature setting of heater plate and N2 shown in Figure 4.1. Mount inline temperature on sample is checked on 3-point (First/Middle/End) which is channel 1 (CH1), channel 2 (CH2) and channel 3 (CH3) using thermocouple as per below illustration on reference and evaluation sample for QFP(CU) 0707 and QFP(CU) 1010 package.

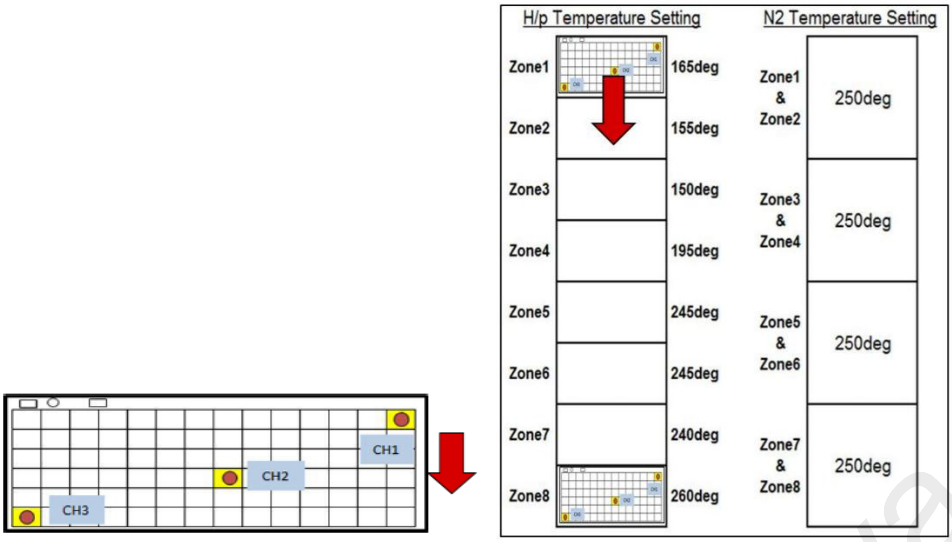


Figure 4.1: Lead frame direction in zone 1 ~ zone 8 and their temperature setting

Based on mount inline cure result shown in Figure 4.2~4.5, there is separation on the mount in-line cure for stage 5 for widen lead frame sample of QFP(CU) 0707. Channel 1 (CH1) and channel 3 (CH3) show higher temperature compare to another channel (CH). No significant different on temperature distribution for reference sample. However, all measurement is within specification. It happens on widen lead frame of QFP(CU) 0707 sample only, while QFP(CU) 1010 sample has no separation on temperature on stage 5.

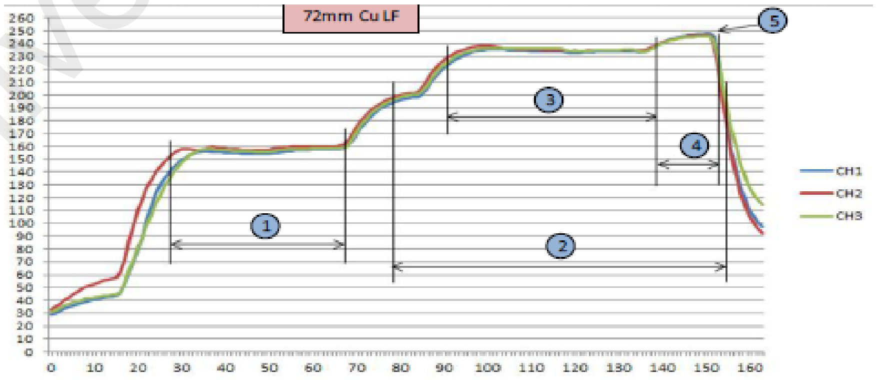


Figure 4.2: Mount inline cure temperature for QFP(CU) 0707 (Reference sample size: 72mm x 223.4mm)

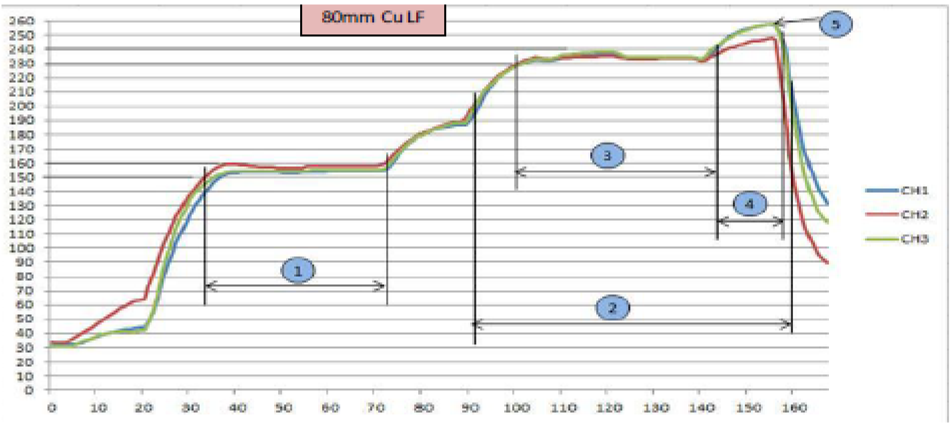


Figure 4.3: Mount inline cure temperature for QFP(CU) 0707 (Evaluation sample size: 80mm x 250mm)

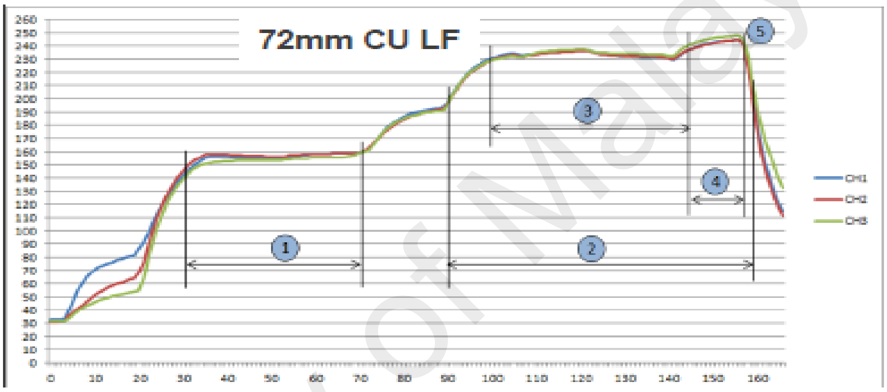


Figure 4.4: Mount inline cure temperature for QFP(CU) 1010 (Reference sample size: 72mm x 223.4mm)

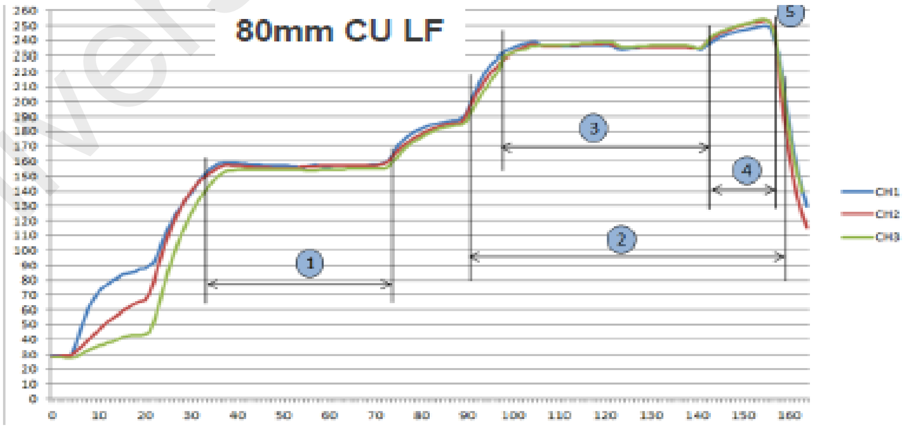


Figure 4.5: Mount inline cure temperature for QFP(CU) 1010 (Evaluation sample size: 80mm x 250mm)

4.1.1.1 Analysis

(a) ***Analysis 1: Check another check point (Placed horizontally)***

Based on finding of heat distribution at mount inline cure process, temperature at zone is higher at channel 1 (CH1) and channel 3 (CH3). So, we continue check on another check point and place it horizontally as per below Figure 4.6 illustration. No significant different on the heat distribution at zone 5 for horizontal check point. This is show that the temperature only impact at edge area that far from the center.

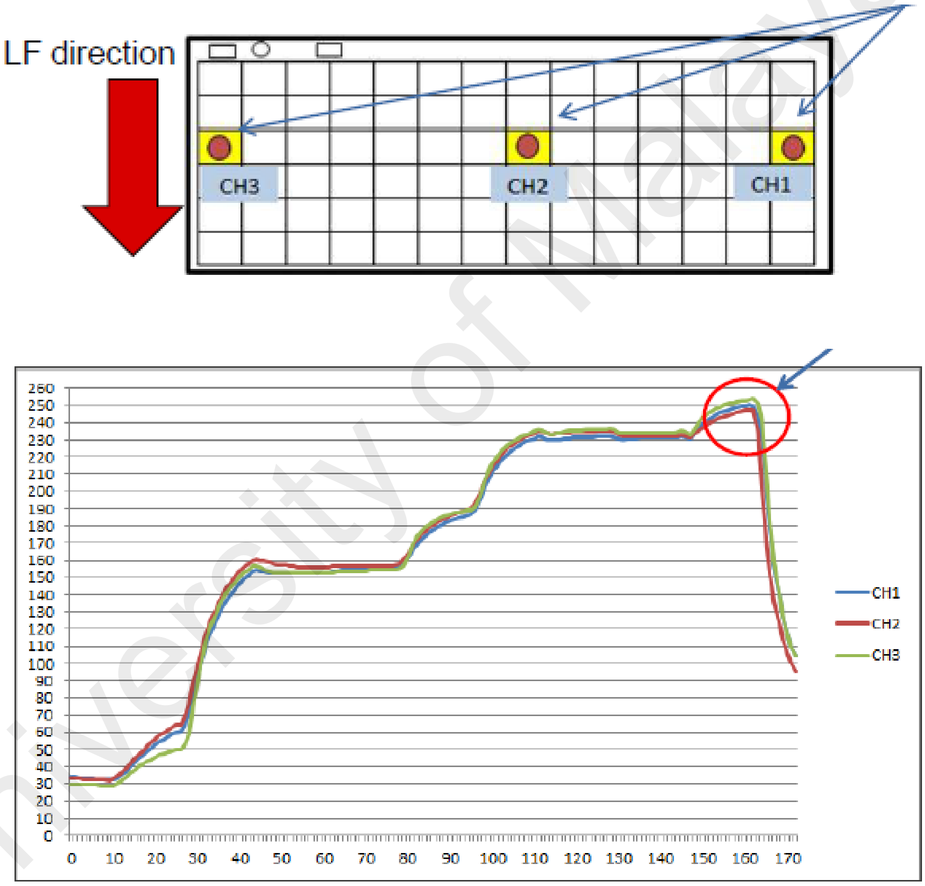


Figure 4.6: Illustration position check point and their result

(b) ***Analysis 2: Re-do for verification***

Re-do also show the separation on heat distribution for channel 1 and 3 at zone 5.

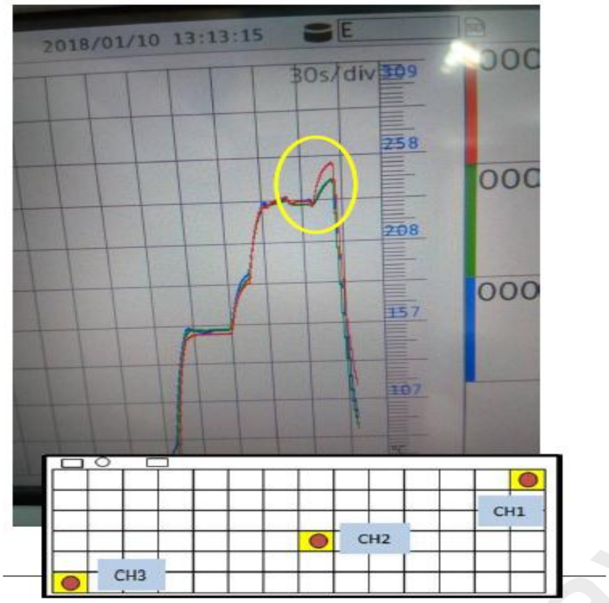


Figure 4.7: Re-do profile verification

(c) ***Analysis 3: Verification on actual heat on heater plate***

Temperature distribution on heater plate is checked by thermo-couple at all 9 point. Based on temperature result shown in Figure 4.8, it is confirming that no significant different on actual temperature on heater plate and no mechanical problem is occurred in zone 5. The differences on temperature are only +/-2 degree Celsius.

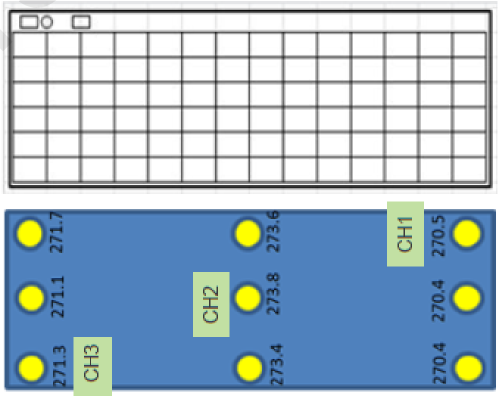


Figure 4.8: Actual temperature on heater plate

4.1.1.2 Failure Mechanism

At the zone 5, heater plate temperature is 245 degree Celsius and it gives full coverage on all bottom area of the lead frame. On top of the lead frame, there is nitrogen supply at the center of lead frame. Figure 4.9 show the illustration of nitrogen gas blow position in the inline cure chamber. Nitrogen gas (N2) is blow on the center and channel 2 (CH2) with 250 degree on the center and push the hot air to channel 1(CH1) and channel 3 (CH3). Channel 2 (CH2) cooling faster compare to another channel. This phenomenon gives high temperature for channel 1(CH1) and channel 3 (CH3) point. Due to wider size, it shows differences on the temperature at area far from the center point.

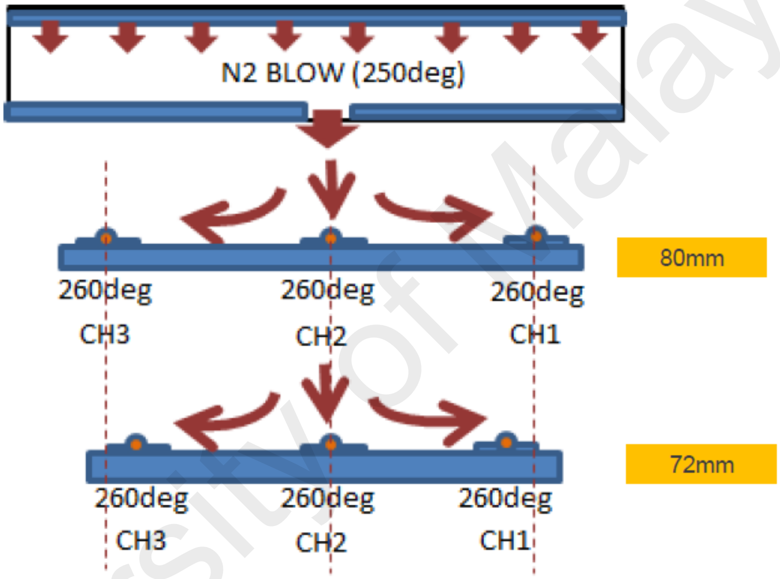


Figure 4.9: Illustration of nitrogen gas blow position in the inline cure chamber

Factor warpage also one of the concerns after apply heat. High density unit per lead frame may contribute for warpage and it cannot be avoided. Widen lead frame of QFP(CU) 0707 sample (84pcs/ lead frame) has high density unit per lead frame compared to QFP(CU) 1010 sample (60pcs/lead frame), warpage ratio is increase and heat distribution uneven also obvious.

4.1.2 Bonding temperature distribution

At bonding process, actual temperature is measured for each unit row for one column. Reference sample of QFP(CU) 0707 package has 12 column x 5 row

(60pcs/lead frame) while evaluation widen lead frame has 14 column x 6 row (84pcs/lead frame). And for QFP(CU) 1010 package, it has 10 column x 4 row (40 pcs/lead frame) for reference sample and 12 column x 5 row (60 pcs/ lead frame). Result of actual bonding temperature is shown in Table 4.2.

Table 4.2: Actual bond temperature measurement

		QFP(CU) 0707		**QFP(CU) 1010**	
	Row	**Reference**	**Evaluation**	**Reference**	**Evaluation**
Actual bond temperature (˚C)	1	204	206	201	209
	2	208	208	210	210
	3	210	210	210	214
	4	207	209	201	210
	5	204	208	-	208
	6	-	205	-	-
	Ave	**207.2**	**206.2**	**205.5**	**210.2**

Temperature unit at row 3~4 is higher compare to temperature unit at first and last row for both samples. The differences are +/-4 degree Celsius

4.1.2.1 Failure mechanism

Figure 4.10 show the illustration and dimension for heater element. Sic (Silicon carbide) heating element are rod shaped or tubular depend on their diameter. They have central heating section referring to hot zone and two terminal sections called cold end zone. The cold end formed with low resistance contact surface for electrical connection to ensure reliability and trouble-free operation. As heater element principle where both edge have the CZ (cool zone) & center as HZ (hot zone) (Mart, 1996). Column far away from heater have low temperature. Reason for this phenomenon center temperature higher compare to last column is temperature lost through environment as edge heater plate is exposing more to the surrounding compare to center. So, wider lead frame heating rate is slower compared to original size of lead frame.

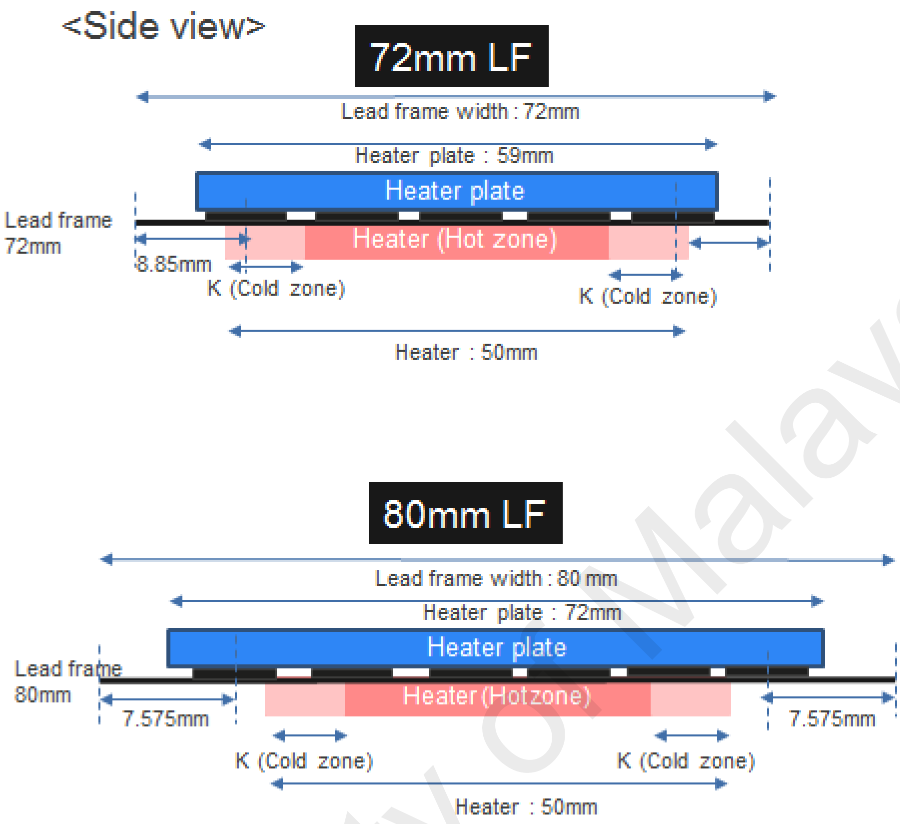


Figure 4.10: Illustration and dimension for heater element

4.1.3 IMC (Inter metallic) check

IMC is calculated in percentage by software. Based on IMC result in Figure 4.11~4.12, widen lead frame has minimum IMC percentage for widen lead frame is slightly lower compare to reference lead frame. This is because of heat loss especially for that column unit that far away from center. However, if comparing to average value, no significant different on both samples.

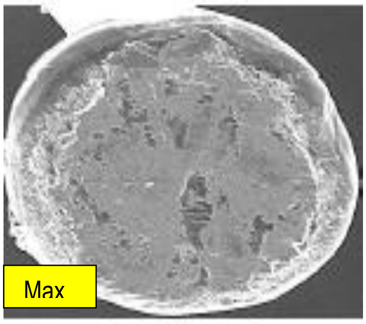
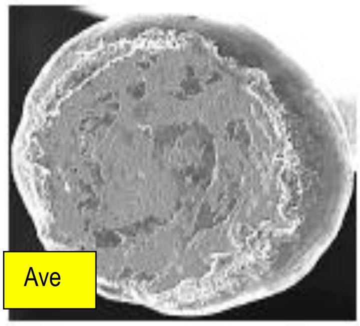
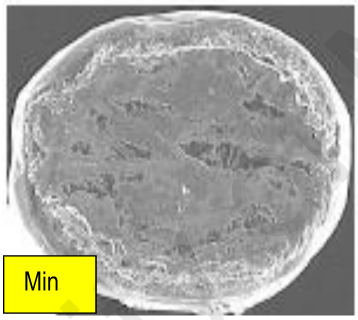
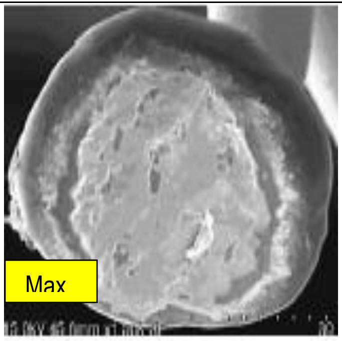
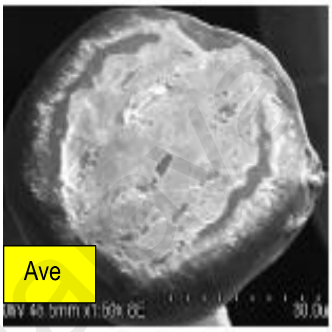
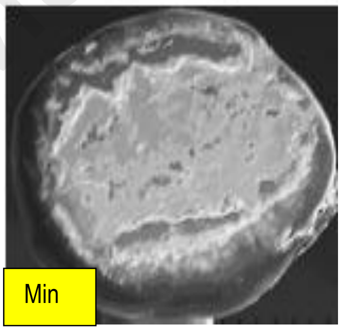
IMC	Reference	Evaluation
IMC photo of QFP(CU) 0707 package	  	  
Max	94.44 %	88.55 %
Ave	81.95 %	82.78 %
Min	77.33 %	72.14 %

Figure 4.11: IMC result for QFP(CU) 0707 package

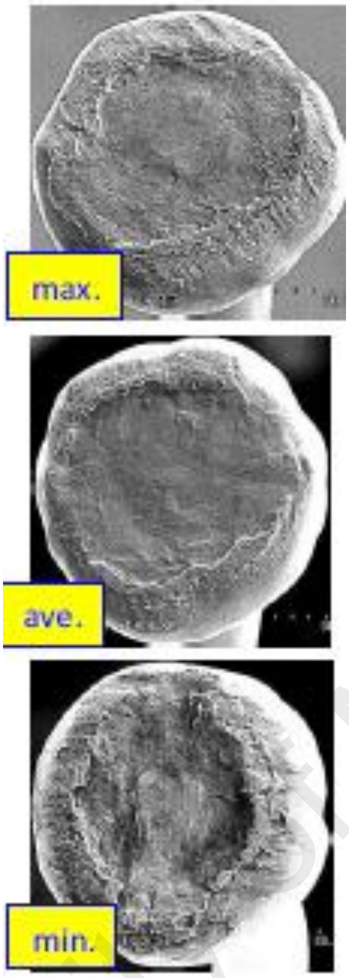
IMC	Reference	Evaluation
IMC photo of QFP(CU) 1010 package		
Max	88.92 %	86.43 %
Ave	83.12 %	83.29 %
Min	74.56 %	72.33 %

Figure 4.12: IMC result for QFP(CU) 1010 package

4.1.4 Wire pull strength

For first bond, wire pull strength slightly lower for widen lead frame compare to reference sample due to heat loss especially unit column far away from center. No significant different for reference and evaluation sample for both package on second bond wire pull result. Comparison result shown in Figure 4.13 ~ 4.16.

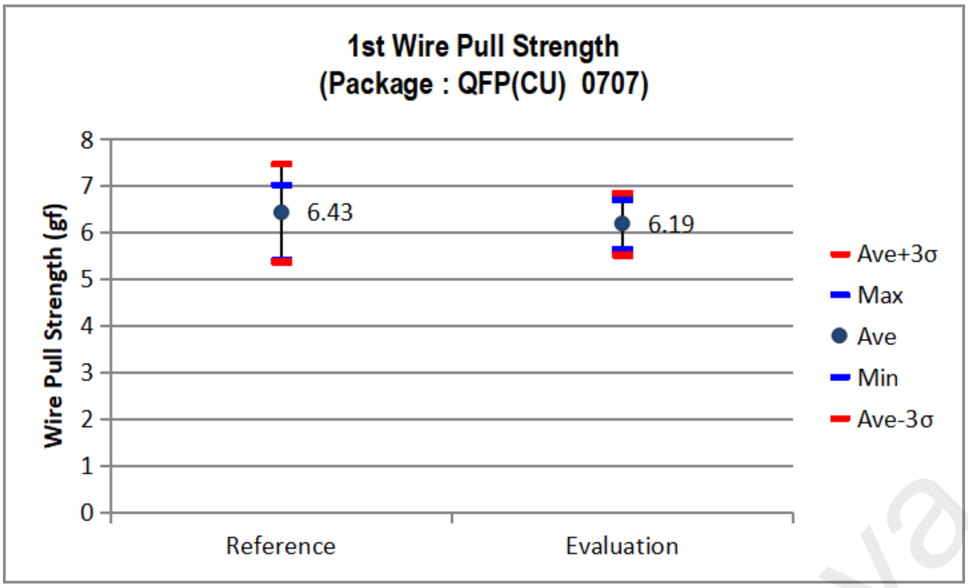


Figure 4.13: First wire pull strength for QFP(CU) 0707 sample

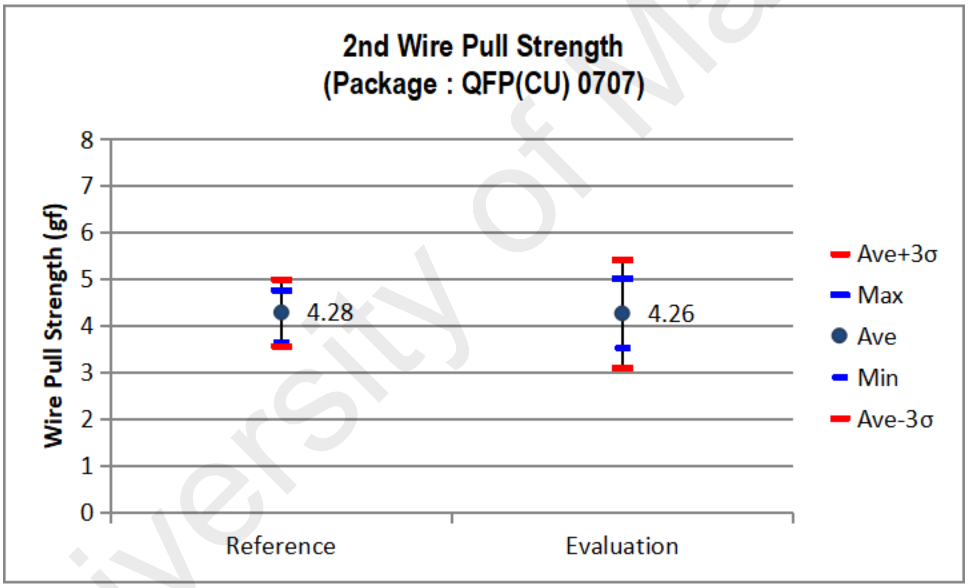


Figure 4.14: Second wire pull strength for QFP(CU) 0707 sample

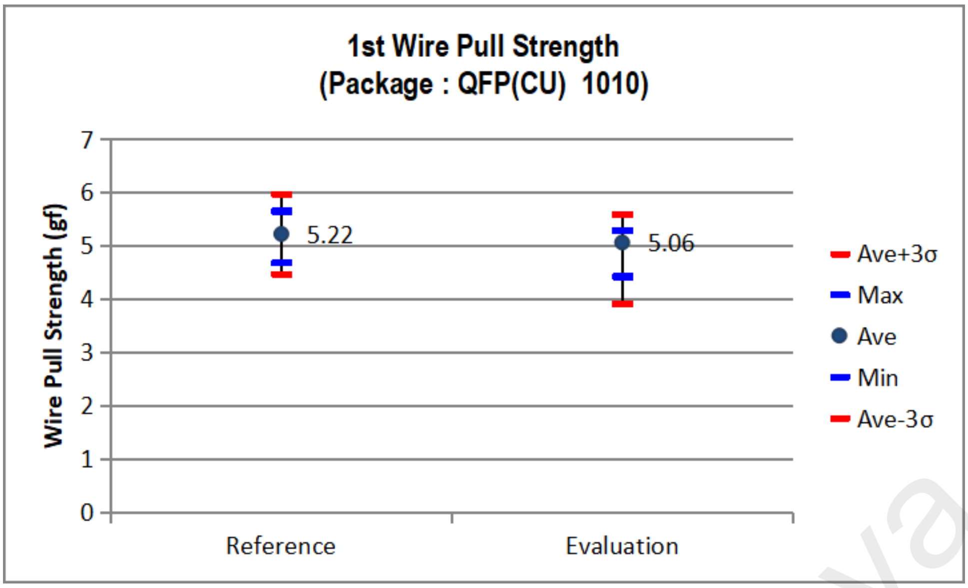


Figure 4.15: First wire pull strength for QFP(CU) 1010 sample

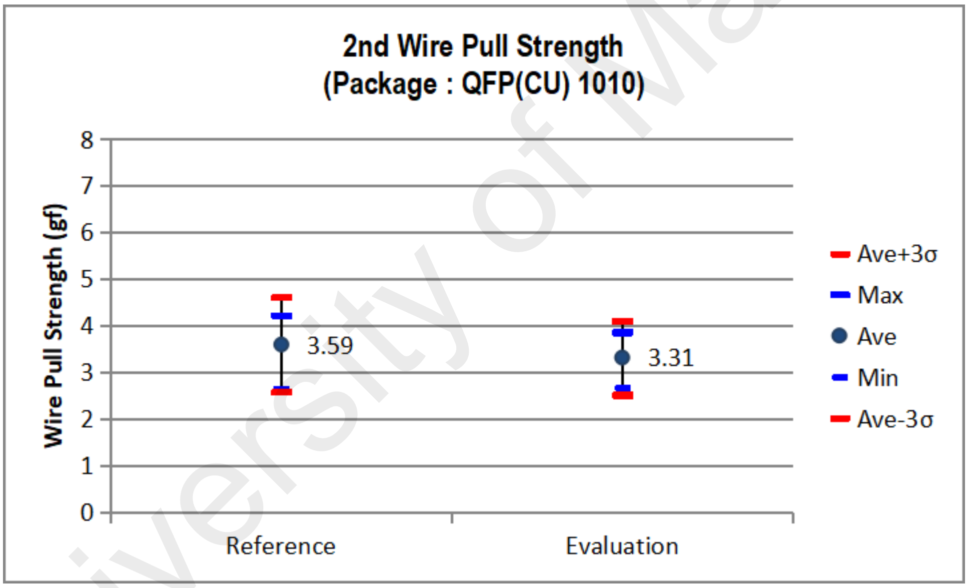


Figure 4.16: Second wire pull strength for QFP(CU) 1010 sample

4.1.5 Ball shear strength

No significant different on ball shear strength for both sample in Figure 4.17~4.18. Ball shear is depending on ball thickness or total sheared volume. No relation on heat distribution of the lead frame. If the ball thickness is almost same for reference and evaluation sample, ball shear also gives the same range.

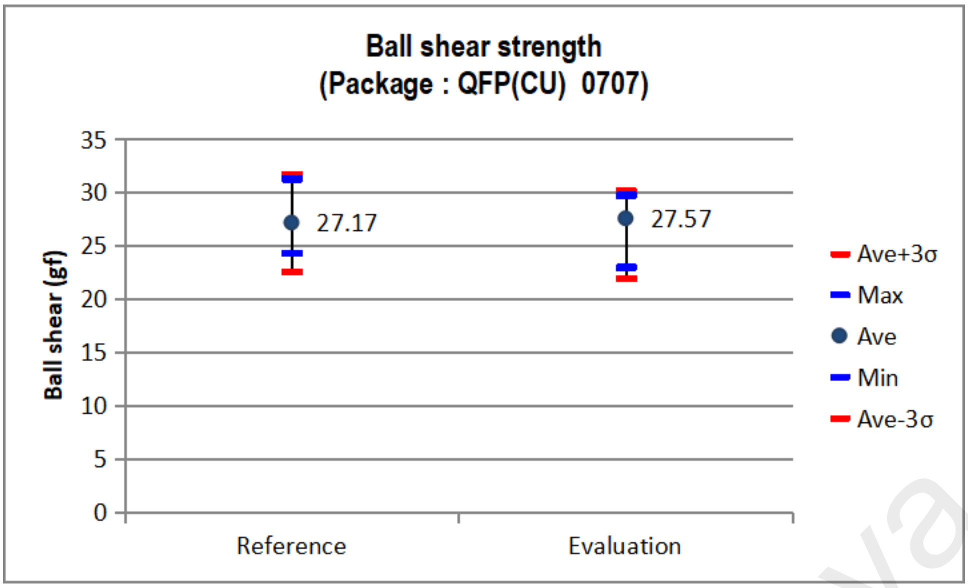


Figure 4.17: Ball shear for QFP(CU) 0707 sample

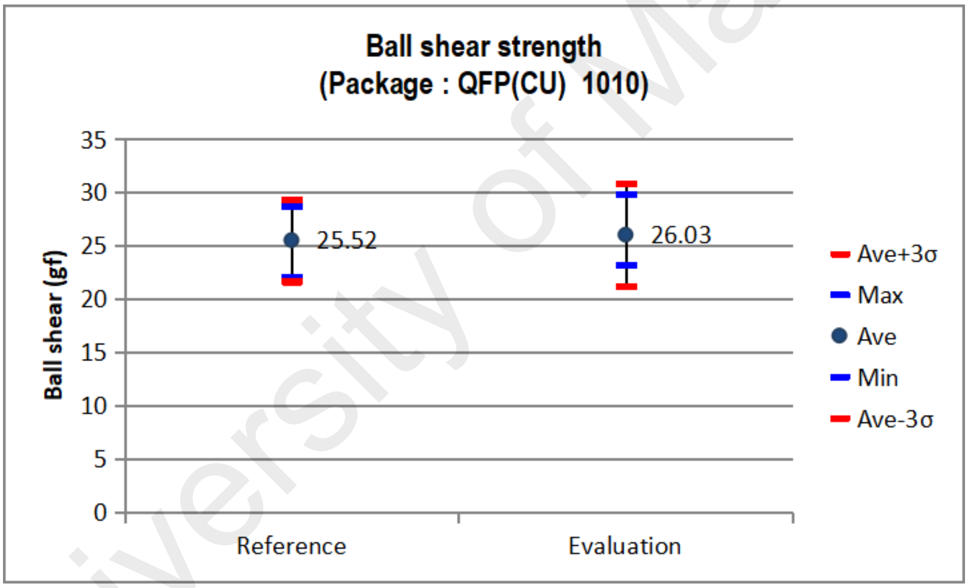


Figure 4.18: Ball shear for QFP(CU) 0707 sample

4.1.6 Ball size

Free air ball size consistency, controlled by the EFO. During gold ball wire bonding, adequate amounts of pressure, heat, and ultrasonic forces are applied to the ball for a specific amount of time. It is forming the initial metallurgical weld between the ball and the bond pad as well as deforming the ball bond itself into its final shape.. In this case, they run at the same bonder with same parameter, and the actual temperature differences at bonding process is only +/-4 degree Celsius, no significant difference on ball size X, Y and Z for both samples in Figure 4.19 ~ 4.21.

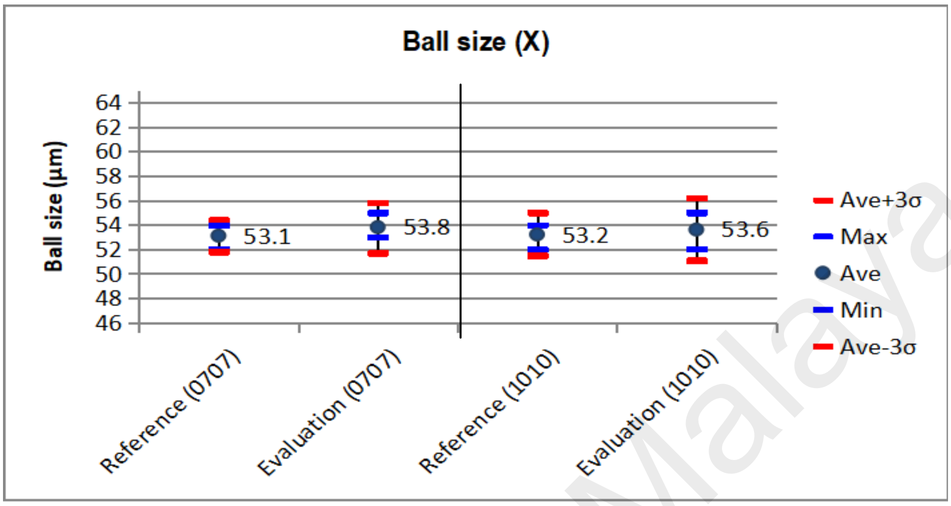


Figure 4.19: Ball size (X) dimension

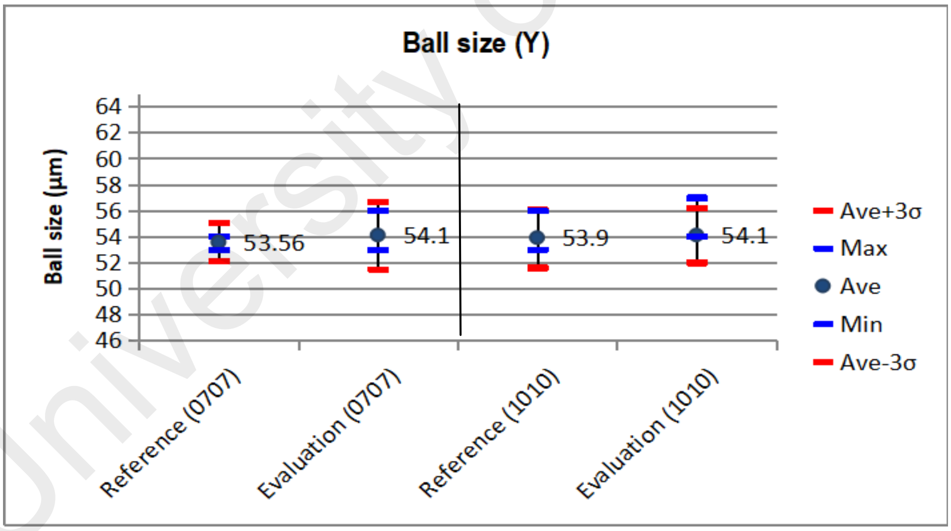


Figure 4.20: Ball size (Y) dimension

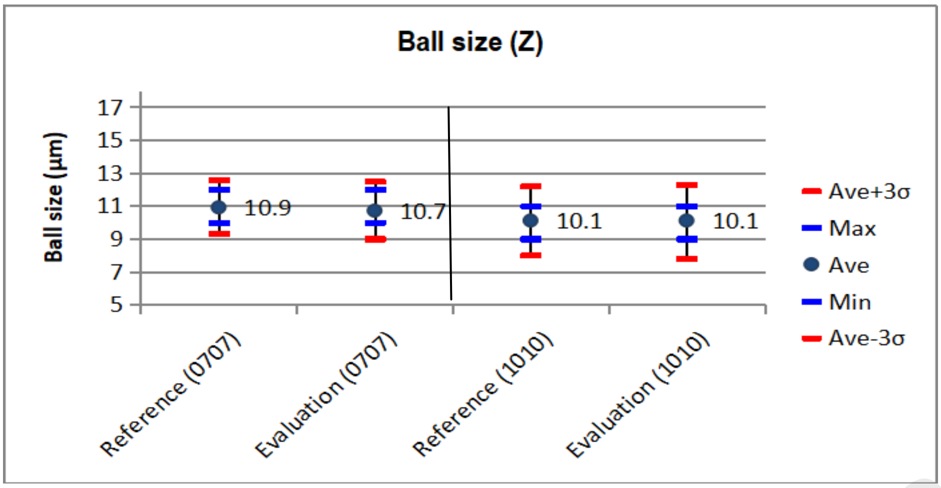


Figure 4.21: Ball size (Z) dimension

4.2 Effect of vibration on lead frame size

4.2.1 Visual inspection

100% visual inspection and 100% functional test is performed at mount, bond and test. Based on this result, 4 pcs of wire related defect which is D-point cut is detected on evaluation sample for QFP(CU) 0707 package. For QFP(CU) 1010, no defect is detected. Summary result is shown in Table 4.3.

Table 4.3: Summary visual inspection result for mount, bond and testing

Process	QFP(CU) 0707		QFP(CU) 1010	
	Reference	Evaluation	Reference	Evaluation
Mount	100% (180/180pcs)	100% (420/420 pcs)	100% (120/120pcs)	100% (300/300pcs)
Bond	100% (180/180pcs)	100% (416/420 pcs) D-point cut-4 pcs	100% (120/120pcs)	100% (300/300pcs)
Testing	100% (180/180pcs)	100% (420/420 pcs)	100% (120/120pcs)	100% (300/300pcs)

4.2.2 Loop height

Loop height setting same for all sample. No significant different on the loop height result.

4.2.2.1 Analysis

Wire cut at D- point happen near to second bond area. Figure 4.22 show the illustration of side view for wire cut position. Defect mainly happened at row 1 and row 5 at quadrant 4 (6 o’clock direction).

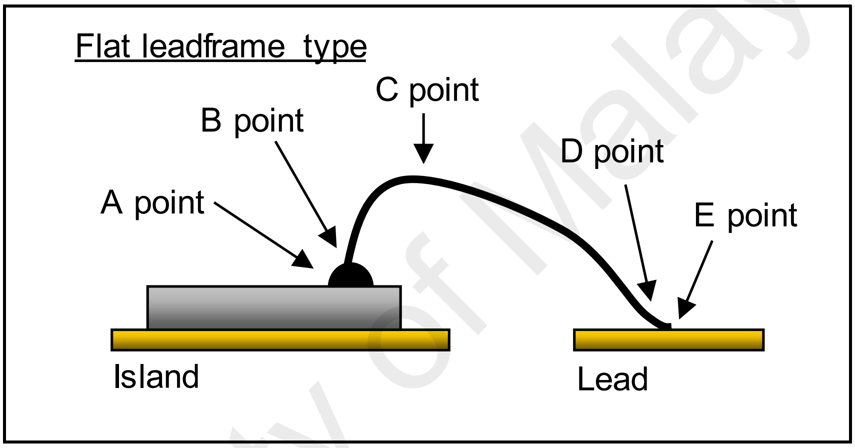
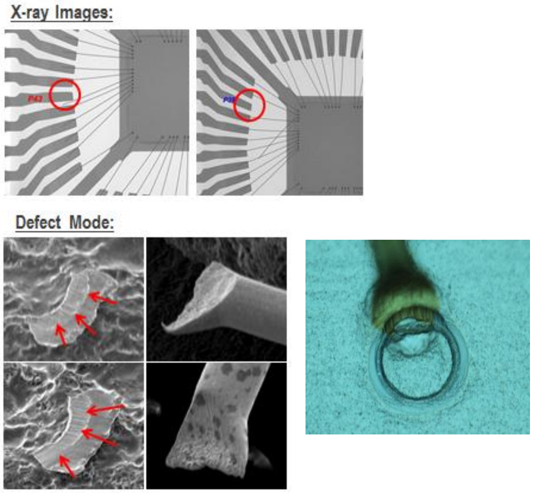
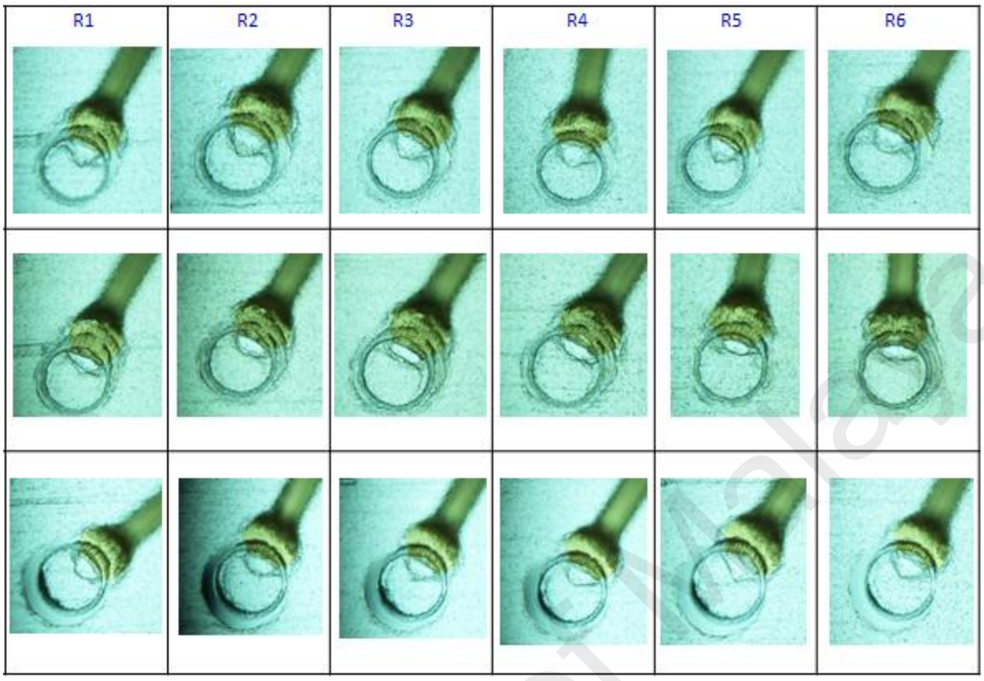


Figure 4.22: Illustration side view of wire cut position

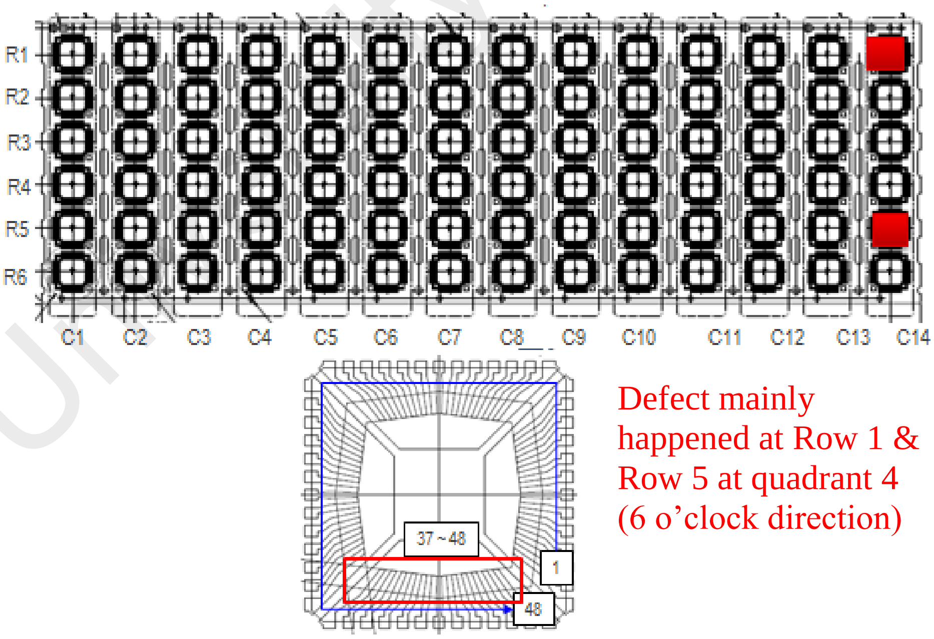
Figure 4.23 show the detail defect photo and defect mapping. On the second bond area, skidding mark by capillary is observed especially at row 1 and row 5 at quadrant 4 position.

(a) Defect photo





(b) Defect mapping

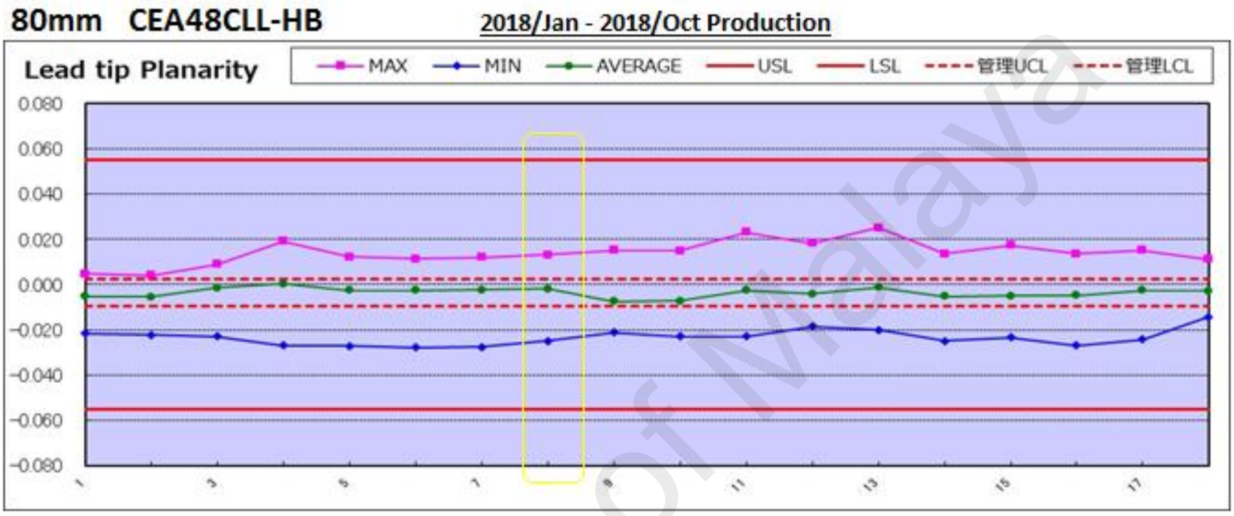


Defect mainly happened at Row 1 & Row 5 at quadrant 4 (6 o’clock direction)

Figure 4.23: Defect photo and defect mapping

(a) ***Analysis 1: Lead tip planarity comparison***

Figure 4.24 shows the lead tip planarity comparison on the reference and evaluation sample based on production lot. Based on this result, 80mm x 250mm size lead frame having bigger variation of lead floating as compared to 72mm LF (same inner lead design)



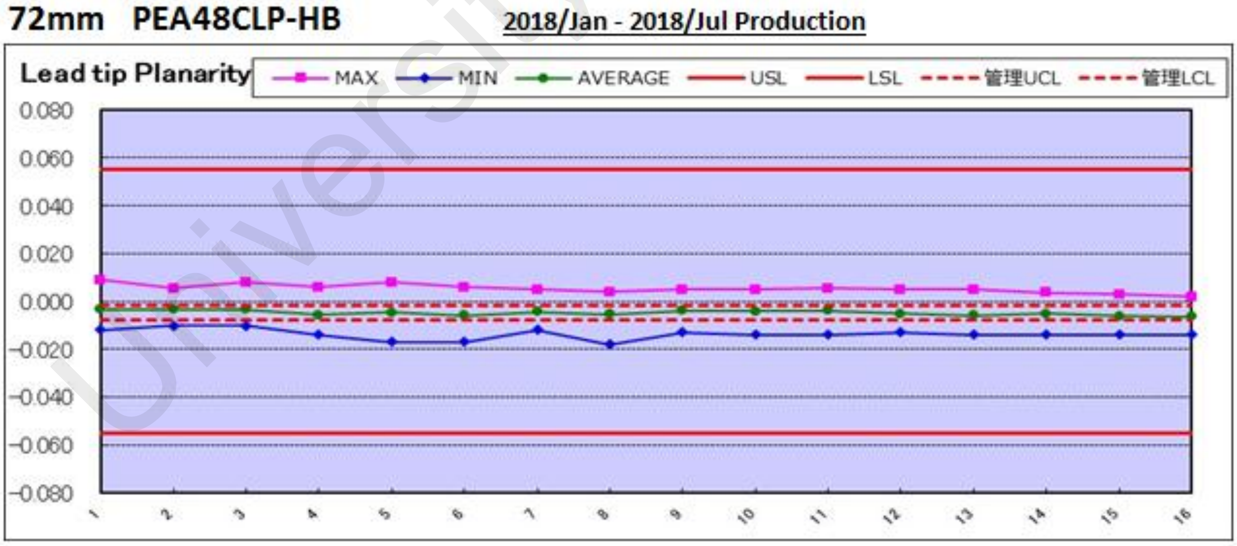
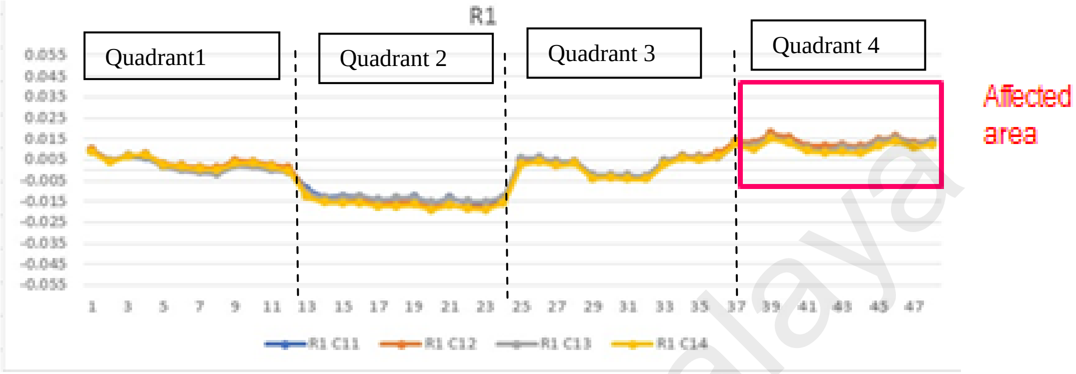
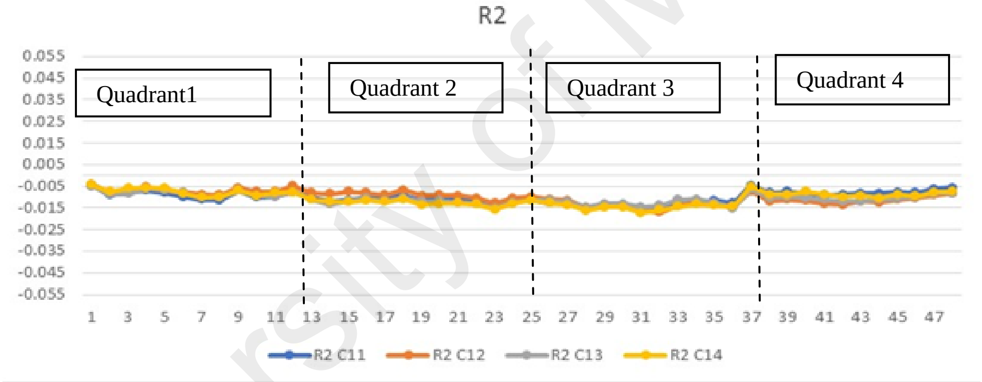


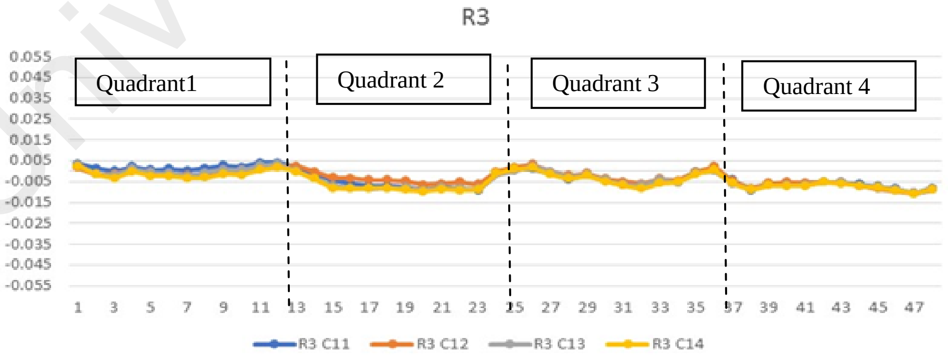
Figure 4.24: Lead tip planarity for reference and evaluation sample of QFP(CU) 0707 package

(b) *Analysis 2: Lead floating based on row*

Analysis on lead floating is performed for each row of widen lead frame. Figure 4.25 show the lead floating data of lead at row 1 ~ 5 for QFP(CU) 0707 package. Affected area is having positive (+) lead floating (upward).







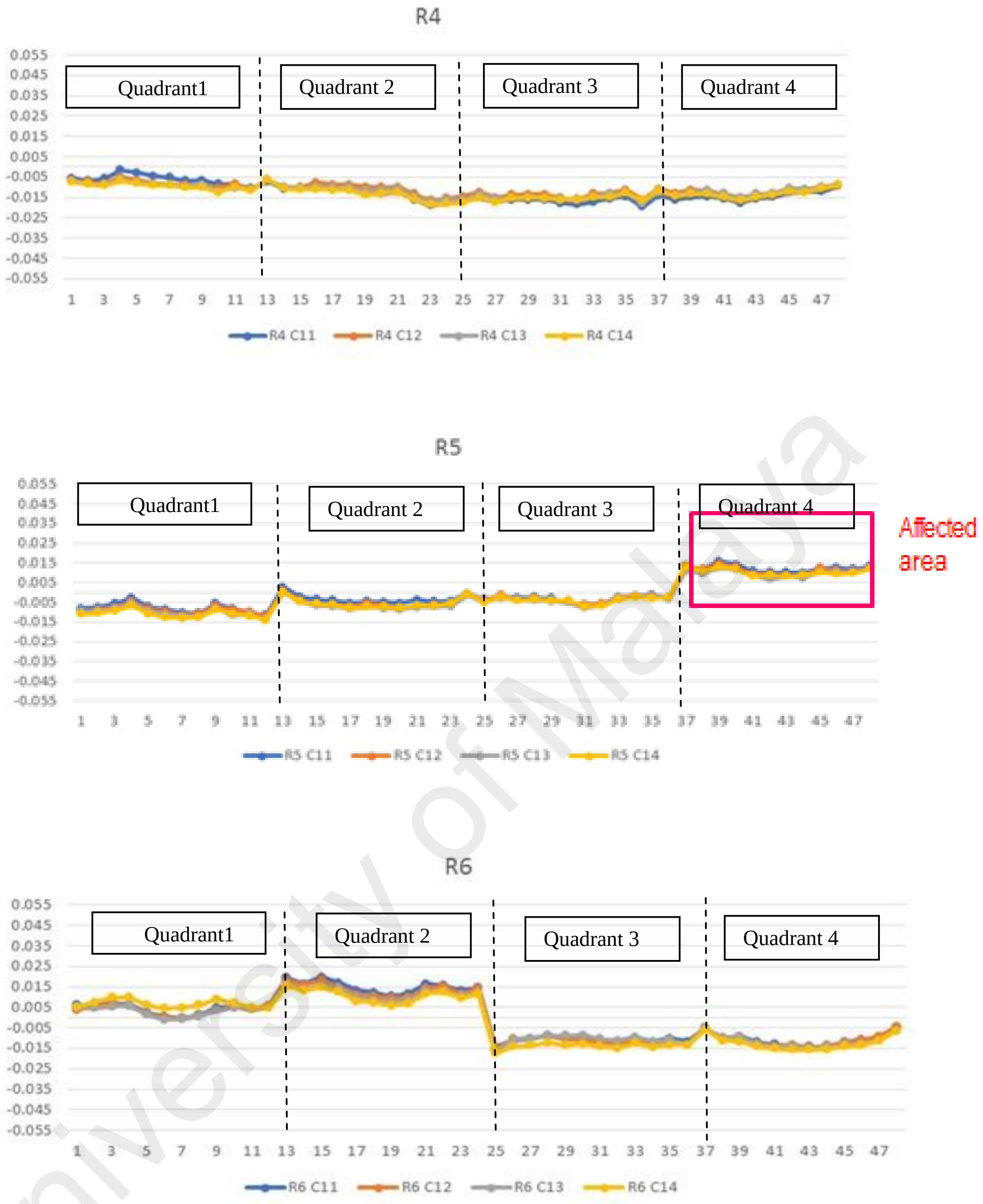


Figure 4.25: Lead floating data for unit at row 1 (R1) ~ row 5 (R5)

(c) *Analysis 3: Row by row comparison by 3D measurement*

For further analysis, row by row comparison by using 3D measurement is performed and show as per Figure 4.27. Lead at row 1 show differences on the color contour at quadrant 2 and quadrant 4. It shows lead is downward trend at quadrant 2 and upward trend at quadrant 4. Color tone lead at 4 side quadrant is almost same at row 2, row 3 and row 4, shows that lead planarity is even at 4 side of quadrant. For unit at row 5, lead is upward trend at quadrant 4 while unit at row 6 have lead upward trend at quadrant 1 and 2.

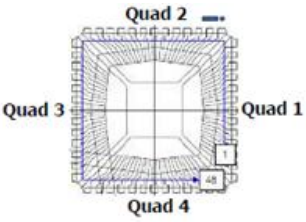


Figure 4.26: Illustration of quadrant position

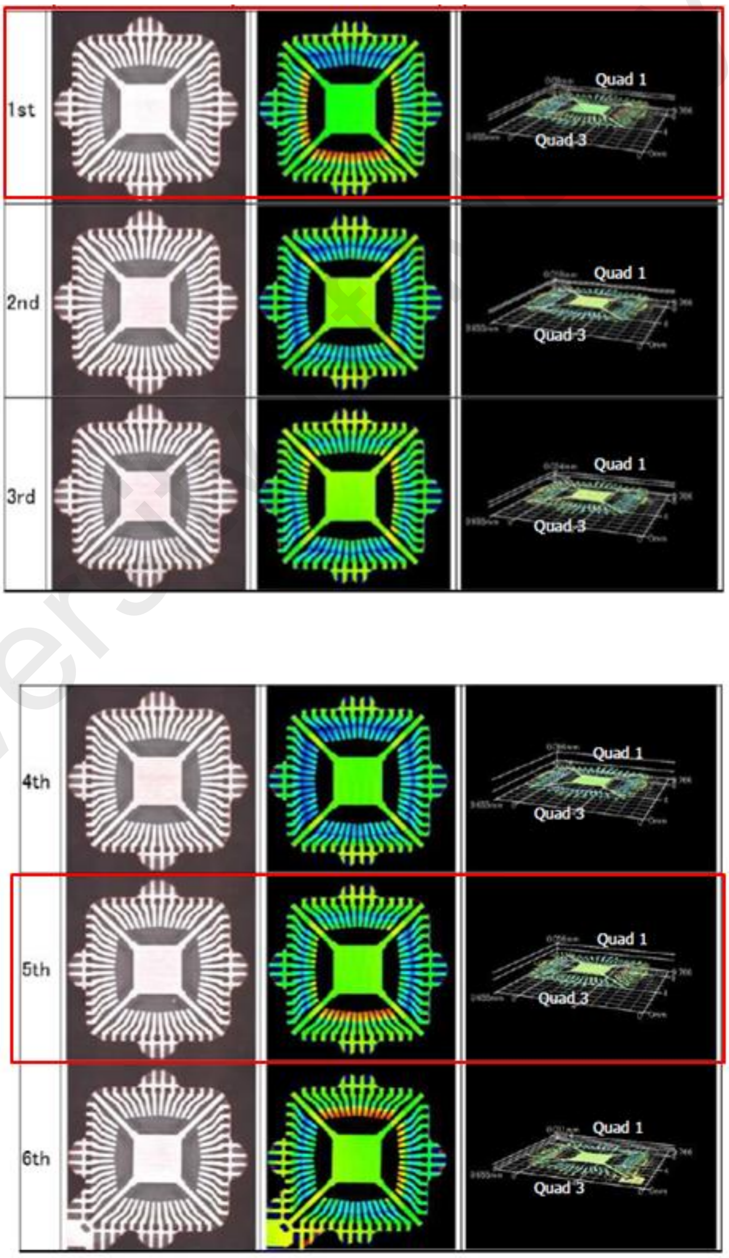


Figure 4.27: 3D measurement result and color contour for unit at row 1 ~row 6

(d) *Analysis 4: Row by row comparison by profile measurement*

To understand the detail of inner lead profile, profile measurement at specific lead on #19 (at quadrant 2) and #4 (at quadrant 4) is performed in Figure 4.28. As result, lead upward trend at quadrant 4 in Row 1 and quadrant 4 in row 5 is observed. The analysis is supported with affected wire defect location which is happen on quadrant 4 in row 1 and row 5.

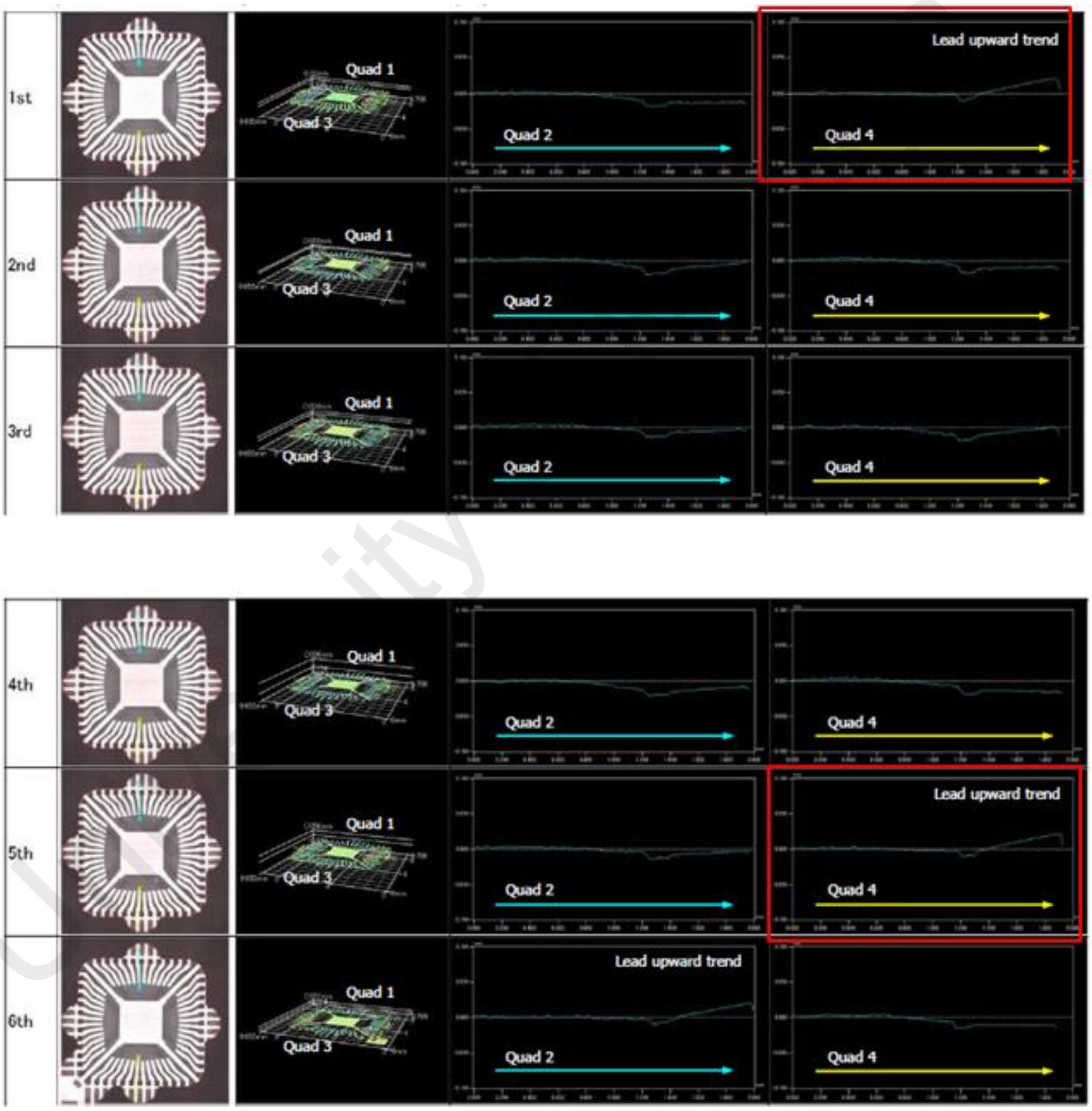
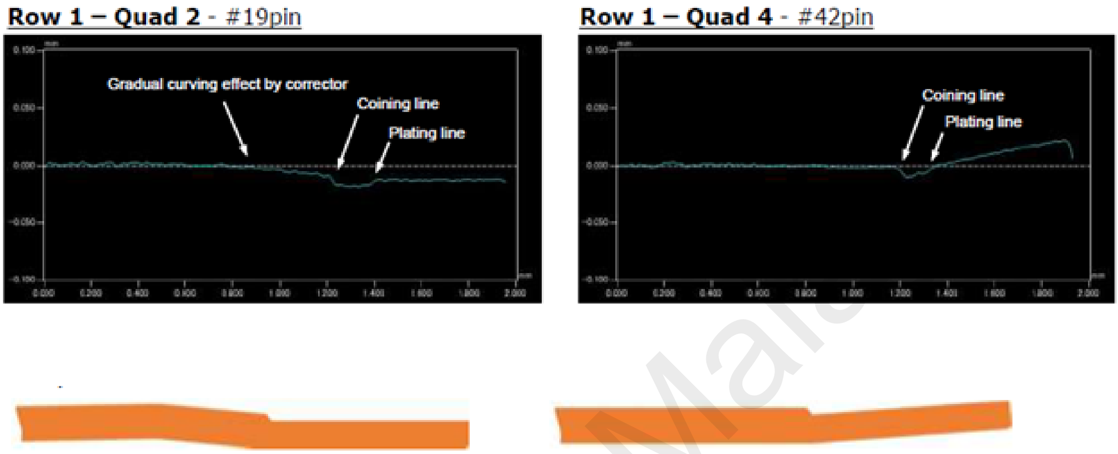


Figure 4.28: Row by row comparison by profile measurement

4.2.2.2 Failure mechanism

Lead tends to bounce during bond process. Due to this phenomenon, capillary will skid, and skidding mark will occur at second bond. In Figure 4.29 show structure of lead upward and downward and their mechanism.



a) Lead flat

b) Lead upward

Figure 4.29: Structure of lead flat, upward and downward

It is nature of stamping process having upward lead floating condition after finish punching process due to stamping mechanical stress inside the material. Lead profile at Figure 4.29 (a) show the flat lead planarity for pin #18 at row 1, (quadrant 2) and no observed upward or downward trend at lead tip side. However, this trend is created by gradual curving at middle area of inner lead. During wire bonding process, clamper will hold inner lead and the lead profile become flatten. With this condition, bonding performance is good. Lead profile at Figure 4.29 (b) shows upward trends at lead tip side. When clamper hold the inner lead, lead floating upward will increase. With this condition, by pressing the finger lead with bonding capillary at second bond, the finger lead will be bouncing and give negative impact on second bond ability. Skidding mark will make the second bond ability weak and wire cut will occur. Under high speed camera, we can observe lead bouncing during wire bond at affected area as per shown in Figure 4.30 for illustration of floating lead.

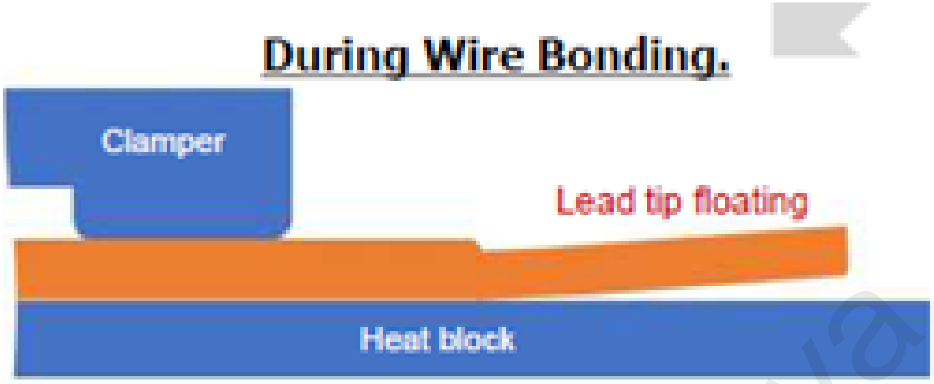


Figure 4.30: Illustration of floating lead condition after clamp during bonding

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Heat distribution

Imbalance of heat distribution on widen lead frame cause warpage problem that will give impact on quality performance especially during mount inline cure and bonding process. For mounting process, nitrogen gas blow at center of lead frame, so center cooling faster compares to other area. At the same time, it will push the hot air to first and last column of lead frame. By this phenomenon, temperature at the first and last column slightly higher compare to center area of lead frame. Due to size of lead frame wider for evaluation sample, the cooling rate is slower compare to original reference sample. However, the lead frame shape behavior will back to original structure after taking out from mounting machine and expose to room temperature. We can see this temperature differences obviously on high density package. For bonding process, heater plate and work-holder heating principle, temperature at the center lead frame is higher compare area that far away from center portion and some warpage happens. This phenomenon contributes less bonding strength for those areas that far away from center portion. For recommendation improvement, add in more hole at mount inline cure machine for nitrogen gas blow in order to expedite the cooling rate for the whole lead frame and some modification on the design of lead frame especially down-set design installation may help to release the stress and warpage reduction (Oscar, 1985).

5.2 Vibration

Lead floating is nature for stamping lead frame and difficult to align lead planarity to fine optimum level for widen lead frame size. For lead floating with upward trends, the finger inner lead will be bouncing during bond process and causing skidding. This skidding impact will weaken the second bond ability performance (Clauberg, Chylak, Wong, Yeung, & Milke, 2010) and second bond wire related defect will happen. Function on coining punch is to flatten the plurality of finger inner lead and their standard shape is flat and leveling (Lange, 2006). After press using standard shape coining punch in die-set, the lead tip high potential to become upward trend due to coining effect as natural phenomenon of sheet metaling process. For further improvement, modification on coining punch lead frame die-set design for intentionally makes some angle for lead tip in downward condition. With this proposal, theoretically the lead tip will be slightly downward condition and reduce the vibration of widen lead frame.

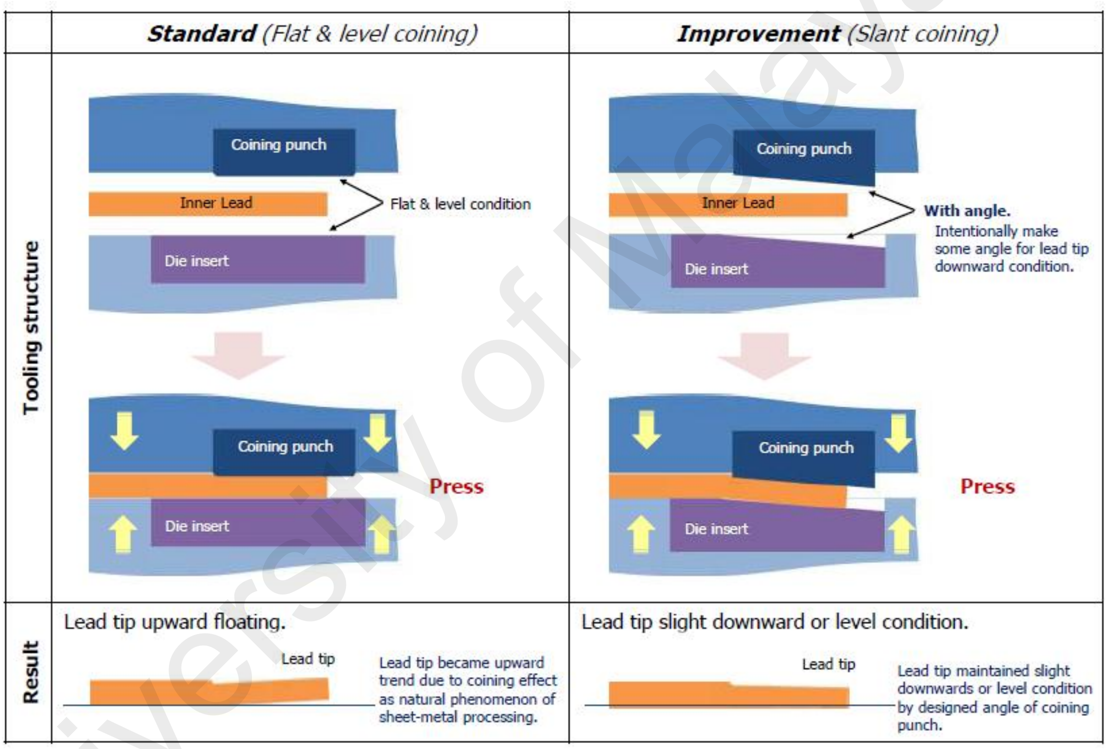


Figure 5.1: Improvement proposal for reduce floating lead upward

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