Presented at IPC Printed Circuits Expo®
SMEMA Council APEX®
Designers Summit 04

Moisture and Reflow Sensitivity Evaluations of SMT Packages as a Function of Reflow Profile at Eutectic and Lead Free Temperatures

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Introduction

Epoxy molding compounds are used extensively in the electronics industry to encapsulate surface mount Integrated Circuits (ICs). The primary purpose of encapsulating the SMT package using these molding compounds is to protect them from adverse conditions. Though the mechanical and electrical properties of epoxy make it suitable for electrical and electronic applications, epoxy is not a hermetic encapsulant and will allow moisture to diffuse into the components. The absorbed moisture affects the properties of the material especially when the components are reflowed and can lead to failures like pop corning and package cracking. Moisture induced reflow failures due to pop corning and delamination in plastic encapsulated SMT packages has been a significant issue in the assembly of PCB's. The impending transition to Printed Circuit Board (PCB) assembly involving more rigorous reflow conditions, accentuates the need for study on the integrity of such packages during and after assembly. This research involves the study of moisture and reflow sensitive behavior of an array of plastic encapsulated packages to assess their performance at both eutectic and lead free reflow conditions

Key Words: Moisture/Reflow Sensitivity, Plastic SMT packages, Eutectic and Lead free Reflow, Preheat Ramp rate, Peak Temperature, Component damage, Delamination, Package Cracking, CSAM

Moisture Induced Reflow Failures – Literature Review

Damage and cracking in plastic SMT packages during assembly on to substrates was first observed in 1985. Since then, major efforts have been made to alleviate this problem.[1] Components stored in an uncontrolled atmosphere absorb considerable amounts of moisture. During reflow, the moisture will vaporize and escape out of the package. The reflow soldering processes, such as vapor phase and IR soldering, have been the predominant historic methods to mount IC's on the PCB's. In modern forced convection reflow the component body reaches a peak temperature of 230-235^{o}C is at the package surface. At reflow temperatures, package cracking and delamination in the interfaces known as 'pop corning' occurs. The moisture in a package produces a two-fold effect.[1]

1. A physical effect due to the rapid vaporization of moisture during reflow, process increases the stress and cracks the package.
2. A chemical effect degrades the encapsulant adhesion with its interface due to the interaction of moisture, which alters intermolecular adhesion.

Moisture induced damage has been found to be influenced by the following parameters.[1]

- Total amount of moisture absorbed by the package;
- Ramp rates and maximum temperature of the heating profile;
- Geometric parameters of the IC package design like die and paddle sizes and package overmold thickness;
- Physical and mechanical properties of the Plastic Molding Compound (PMC) like glass transition temperature T_g, Young's modulus and Coefficient of Thermal Expansion (CTE);
- Adhesion strength at various interfaces such as overmold and die, die and die-attach, lead frame and overmold, die attach and lead frame, die pad and overmold

The interface delamination in moisture absorbed packages subjected to reflow soldering is mainly governed by the thermal stress and the decrease in adhesion strength. This is caused by the moisture absorption rather than vapor pressure.[13] Thinner packages such as TSOPs may be stored indefinitely at low humidity environments. But when the humidity is higher, they become more sensitive to moisture induced damage. The moisture in a plastic-molding compound reaches saturation after a high temperature and humidity soak. For thinner packages, the effect of a moisture gradient before reaching saturation is critical in determining the package's resistance to pop corning and delamination. Accelerated preconditioning stresses can effectively mask the effect of reflow damage in TSOPs.[2] Primarily, it is the molding compound that determines the amount of moisture absorption and adhesion strength.[3] While the conventional epoxy o-cresol novalac materials have been still widely used in packaging, there has been a dramatic change in the development of ultra low stress materials.[1] Specific types of molding compounds are developed to meet requirements for moisture sensitivity as in the case of thin packages. The industry is driving towards the elimination of halides in the molding compound material commonly referred as 'green molding compounds'. This also highlights the focus on the development of green overmold compounds that are highly moisture and reflow resistant. In the development of a molding compound, the challenge is to balance the trade offs in the material properties. The improvement of one property may lead to the degradation of the other. A common trend is to develop a new compound, one optimized to meet the special requirements of a package.[1]

The literature review indicates that avoiding package damage due to moisture absorption and the reflow assembly process are critical aspects in establishing acceptable assembly yield and both the short term and long-term reliability of surface mount packages. Characterizing the behavior of moisture absorption and desorption at different temperatures would enable comprehending the vulnerability of a moisture loaded component at various reflow conditions. The electronics industry is still experiencing problems of moisture induced reflow failures at eutectic reflow temperatures. So there is a critical need for the evaluation of SMT packages at conditions. This research deals with the characterization of typical plastic encapsulated SMT components and a study of their susceptibility at demanding reflow conditions.

Experimental Objective

The objective of this study is to ascertain the effect of moisture and reflow on typical SMT packages. The experimental reflow conditions cover both Eutectic tin/lead and temperature reflow environments. The degradation of moisture-loaded components is assumed to be due to delamination of interfaces, as well as electrical and mechanical failures when subjected to process conditions. This effect and the associated investigation are discussed below.

Experimental Reflow Parameters

The reflow parameters that were considered for the experiments were, peak reflow temperature and preheat ramp up rate. These parameters are assumed to affect the properties of the package materials resulting in degradation of the package.

Preheat Ramp Up rate

Preheat ramp up rate is the rate of increase of the assembly temperature during the preheat zone of the reflow process. This temperature zone ranges from the ambient temperature to about 120^{o}C. The preheat ramp up rate is assumed to affect the rate of vaporization of moisture in a package. High preheat rates could lead to a sudden increase in vapor pressure inside the package forcing interface separations and leading to damage of various levels within the package. The general recommendations are that preheat ramp up rates should be less than 2^{o}C/s or at most 2.5^{o}C/s. At times manufacturing operations use ramp rates that are as 3.5^{o}C/s, which though it is unnecessarily harsh, it is not uncommon.

Peak Reflow Temperature

The peak reflow temperature has a significant effect upon the integrity of the package.[1] Common eutectic (63Sn/37Pb) reflow peak temperatures that component surfaces reach are 225^{o}C-230^{o}C. This is typical for the case of thinner and smaller boards. For large sized and thicker (greater than 100 mils) boards with 10-26 copper layers, the peak temperatures on the component bodies could be as high as 238^{o}C. With the imminent conversion to lead free assemblies, the peak temperatures could be closer to 260^{o}C. Considering potential solder alloys (SAC - 95.5Sn 3.8Ag 0.7 Cu, 93.6Sn 4.7Ag 1.7Cu and SAB - 91.7Sn 3.5Ag 4.8Bi, 90.5Sn 2Ag 7.5Bi), the electronics industry may standardize the use of SAC and SAB alloys for conversion. This SAC alloy solder, depending on its composition, will have a liquidus temperature of 217.1^{o}C or 217.5^{o}C respectively. The SAB alloy will have liquidus temperatures of 202.1^{o}C and 190.6^{o}C respectively.[6] Therefore, the peak reflow temperature that the assemblies could experience is as high as 260^{o}C

Reflow Temperature Profiles

Reflow temperature profiles were developed for the experiments using a test profiling board. Temperature measurements were made on component leads, plastic body, copper pads and solder joints. Two values of preheat ramp up rates were chosen, and are 1.8-2.2^{o}C/S and 3.2-3.5^{o}C/S. Eutectic peak reflow temperatures of 225^{o}C and 235^{o}C and temperatures of 245^{o}C and 260^{o}C were considered. The eutectic 225^{o}C peak temperature limit was considered to establish a baseline for the entire experiment. The experimental parameters and the various parameter levels are shown in Table 1.

The reflow profiles for the experiments were developed in a twelve-zone convection reflow oven. The ramp up rate for this profile was between 3.2-3.5 ^{o}C/s. The preheat region of the profiles were analyzed using the slope markers of the thermal profiling software to identify regions of ramp rate corresponding to 3.2-3.5^{o}C/s. The peak temperature of 217^{o}C on the PWB pads correlated to 225^{o}C on the component body.

Table 1 – Experimental Reflow parameters and Parameters Values

Factors	Levels	Number of Levels
Reflow Peak Temperature	225+/-5^{o}C, 235+/ 5^{o}C, 245+/-3^{o}C, 260+/-3^{o}C	4
Preheat Ramp Up rate	1.8 -2.2^{o}C/Sec, 3.2-3.5^{o}C/Sec	2

Experimental Components

The SMT components for the experiments were of different types to be representative of plastic encapsulated leaded SMT packages. The interconnections from the die to the leads in these packages were through wire bonds. The list of components, the plastic material type and the JEDEC moisture sensitivity classification is shown in Table 2. Cross sectional views of the different packages are shown in Figure 1, Figure 2, Figure 3 and Figure 4. The cross section images show the die attached to the paddle by adhesive. Wire bonds connect the die with the individual leads. The cross section images of optocoupler W and Optocoupler B is shown in Figure 5 and Figure 6. The images show a gel like substance, silicone, in the case of SOIC optocouplers.

Table 2 – Component Details – Overmold Material and JEDEC Classification

Component/Package	Overmold Material	JEDEC MSL
Optocoupler-B, SOIC	Novalac	2
Optocoupler-W, SOIC	White Molding Compound	1
PLCC	Novalac	3
TSOP-S	Novalac	3
TSOP-I	Biphenyl	1
PQFP	Novalac	4

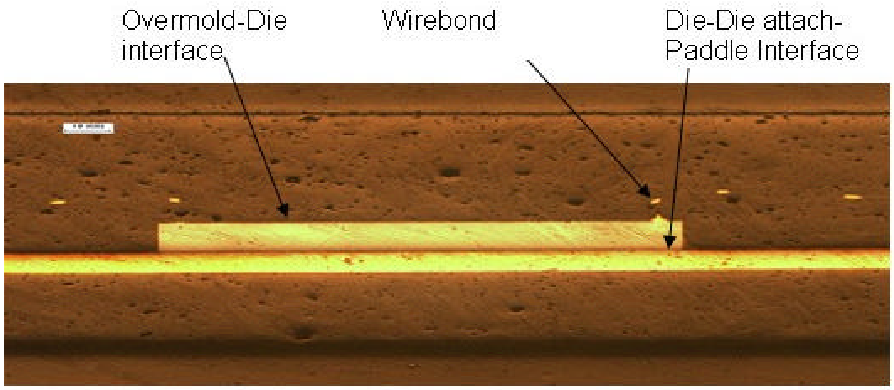


Figure 1 – Cross Sectional Image of PLCC

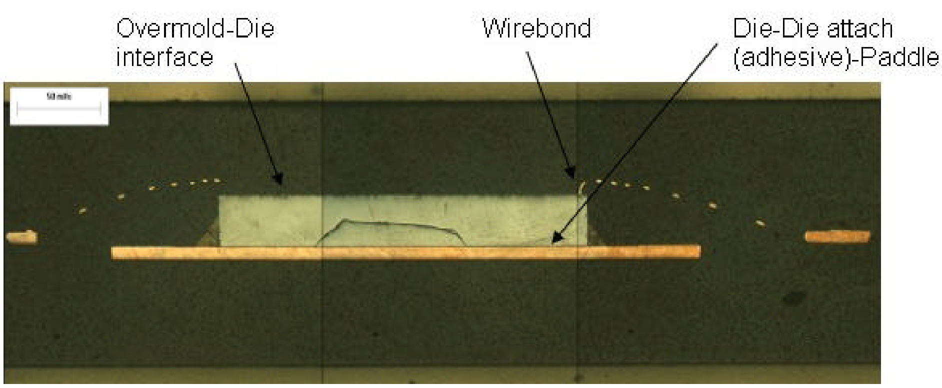


Figure 2 – Cross Sectional Image of PQFP

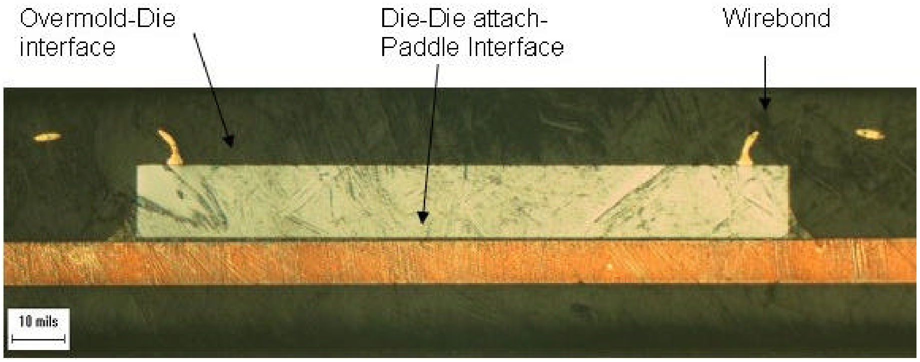


Figure 3 – Cross Sectional Image of TSOP I

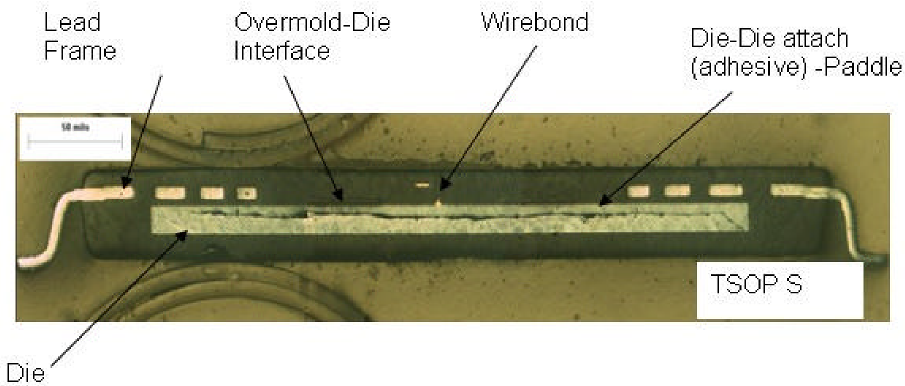


Figure 4 – Cross Sectional Image of TSOP S

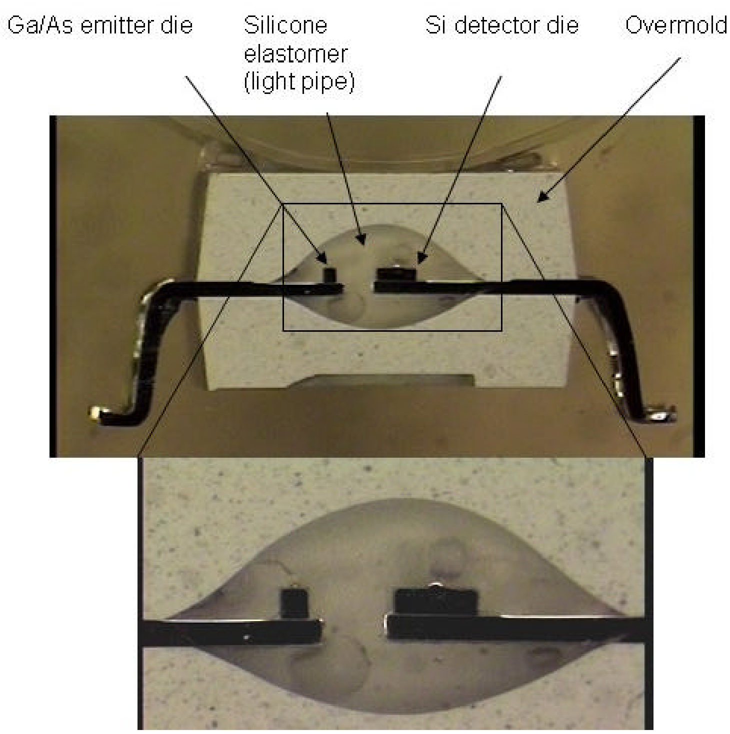


Figure 5 – Cross Sectional View of Optocoupler-W

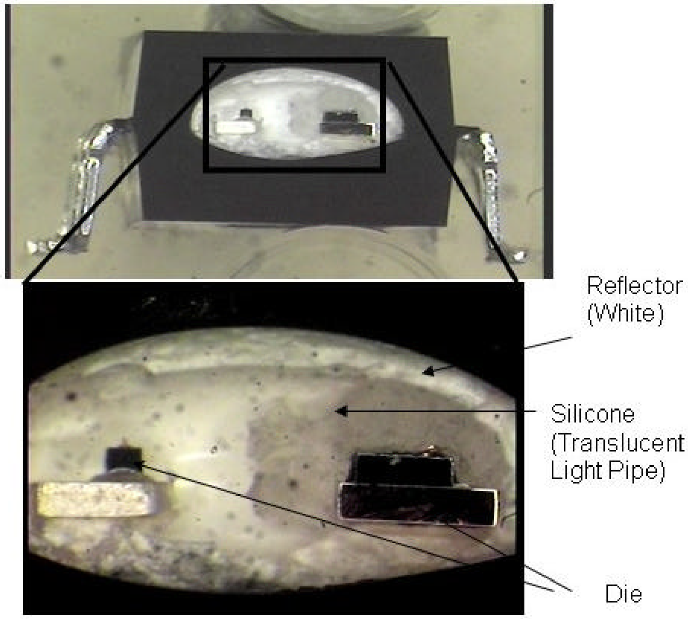


Figure 6 – Cross Sectional View of Optocoupler B -SOIC

Experimental Description

The impact of the process conditions earlier mentioned was determined by reflowing moisture-loaded samples of each component at each condition. The components were moisture loaded based upon the JEDEC specifications.[7] JEDEC standards specify the temperature and humidity and the floor life limit at that condition for each class of components as shown in Table 3. Components Optocoupler W, Optocoupler B, PLCC, TSOP S and PQFP were preconditioned based upon their Moisture Sensitivity Levels (MSL). In another part of the experiment, Optocoupler W, Optocoupler B and TSOP I was de-rated from their MSL and loaded to the condition corresponding to MSL 3. Optocoupler W was also subjected to conditions corresponding to MSL 2. The sample size for each component at each test condition and the level of moisture soak for the components is shown in Table 4. The components were separated at the end of moisture exposure and reflowed three times for the eight different reflow process conditions. JEDEC specifies a three-time reflow to simulate a mixed assembly and rework process. The components were placed on the board used for profiling and reflowed in the convection oven. A five-minute cooling of the processed components was performed subsequent to each reflow. The processed components were protected from Electro Static Discharge (ESD) failure using ESD bags. Depending upon the components, they were subjected to different failure analysis procedures as explained in the following sections.

Table 3 – Component Floor Life Based on Moisture Sensitivity Level (MSL)

Component/ Package	Overmold Material	JEDEC MSL	Floor Life	
			Time, Hours	JEDEC Conditions
Optocoupler-B, SOIC	Novalac	2	1 Year	≤30 ^{o}C/60% RH
Optocoupler-W, SOIC	White Molding Compound	1	Unlimited	≤30 ^{o}C/85% RH
PLCC	Novalac	3	168	≤30 ^{o}C/60% RH
TSOP-S	Novalac	3	168	≤30 ^{o}C/60% RH
TSOP-I	Biphenyl	1	Unlimited	≤30 ^{o}C/60% RH
PQFP	Novalac	4	72	≤30 ^{o}C/60% RH

Table 4- Component Moisture Load Conditions before Reflow

Material /Medium	Acoustic Impedance, Z kg/m^{2}s
Water	1.5 X 10^6 kg/m^{2}s
BGA Molding Compound	2 to 4.5 X 10^6 kg/m^{2}s
Silicon	20 X 10^6 kg/m^{2}s
Copper	42 X 10^6 kg/m^{2}s

Failure Analysis

The processed components using the experimental procedure explained above were analyzed for failures by either electrical test or C-mode Scanning Acoustic Microscopy (CSAM). The test method was based upon the component that was inspected for failure. The construction of optocouplers made it more suitable to use electrical testing and X-ray inspection for the failure analysis. The components that had failed as per the electrical test were re-assessed using X-ray inspection to determine the failure mode. The analysis methodology is explained below.

Electrical Test

Electrical testing was utilized as a failure detection scheme for the two optocouplers in the experiment. Bench test setups were developed for both components based upon their electrical characteristics obtained from the component manufacturer. The bench test circuit for the eight leaded SOIC, optocoupler-B, is explained in the earlier study on the post assembly failure of the optocouplers. The test circuit for the six-leaded DIP, optocoupler-W, is shown in Figure 7. The input current and voltage to the emitter die followed the electrical specifications in the component datasheet. The failure criterion was associated with the resistance measured across the output channels where resistances above 200 ohms were considered a failure. Using the test circuits mentioned above, all of the optocouplers-W and optocouplers-B were tested for electrical failures. The results of the electrical test are shown in Table 6.

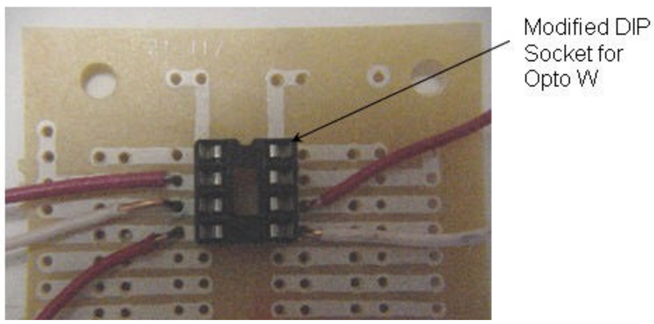


Figure 7 – Test Circuit for Optocoupler W

C-Mode Scanning Acoustic Microscopy (CSAM)

C-SAM is a non-destructive technique useful for detecting voids, gaps and delamination in BGAs, CSPs, flip chip underfill, and plastic surface mount packages. The CSAM uses ultrasonic pulses that are reflected by the various interfacial surfaces. A water bath is used as a coupling medium to propagate ultrasound from the transducer to the component. The ultrasound pulses penetrate the component and are reflected back at interfaces of different acoustic impedance materials. The nature of the reflected pulse depends upon the acoustical impedance of the interface materials. The acoustical impedance of a material is based upon its bulk modulus or rigidity modulus and the density of the material. For example, air has very low density with almost zero acoustical impedance. The acoustical impedance of common packaging materials is shown in Table 5.[5] The transducer that emits the pulses also detects the reflected ultrasound. The traverse of ultrasonic pulses from one material to another typically produces reflections as follows:[5]

- The propagation of ultrasound from high acoustic impedance material on top to a relatively low acoustic impedance beneath produces a negative reflection;
- The propagation of ultrasound from low acoustic impedance material on top to a relatively high acoustic impedance beneath produces a positive reflection;
- The propagation of ultrasound through a delaminated or voided interface produces a total negative reflection of large amplitude as the interface becomes to one of very low acoustic impedance.

With knowledge of the construction of the package and velocities of the ultrasonic pulses in different media, it is possible to set up the equipment to detect delamination at a desired interface. The inference is based upon the scanned image that is defined using a non-defective component. The color map of the scanned image is selected to portray the usual convention that "red implies delamination" and should be investigated further.

The surface mount packages, other than optocouplers, were inspected for die detach or delamination and package cracks using the non-destructive acoustic microscopy technique. The interfaces that were investigated using the 15 MHz transducer were die to adhesive and adhesive to paddle surface. The die to plastic interface was investigated in the case of TSOP-S because of its construction as explained in the earlier sections.

Table 5 – Acoustic Impedance of Common Packaging Materials

Material /Medium	Acoustic Impedance, Z kg/m^2s
Water	1.5×10^6 kg/m^2s
BGA Molding Compound	2 to 4.5×10^6 kg/m^2s
Silicon	20×10^6 kg/m^2s
Copper	42×10^6 kg/m^2s

Acoustic Scanning Procedure for the Components

The initial step in scanning a component is to obtain an image at the top of the sample. This is accomplished by calculating the 'time of flight', which is the focal length of the transducer times a correction factor of 33.3 us/inch. Once the top surface image is obtained, the data gate shift parameter required to view a desired interface is calculated. The data gate shift is given by,

Delta t = 2d/V[5]

Where,

d = desired depth in the sample material in mm (2d since it propagates and gets reflected back);

V = Velocity of ultrasound in the sample material (9.8mm/us for silicon, 2.3-3mm/us for epoxy/underfill materials)

Based upon this equation, the data gate shift parameter for the desired interfaces was calculated for each component and is shown in Table 7. The data gate was positioned at the negative peaks of the waveform for components PQFP, PLCC and TSOP I.

The failure results for the scanned components are shown in Table 6. One out of four PQFPs failed at high peak, low and high ramp rate eutectic reflow conditions. No failures were observed in PLCCs, TSOP, TSOP S and I at the experimental conditions that were considered. The amplitude scan images of the failed and good PQFPs are shown in Figure 8. A negative peak can be seen at the position of data gate in comparison to a good part. Figure 9 and Figure 10 show the scanned images of a PQFP. The dark red patch indicates delamination of the die attach interface.

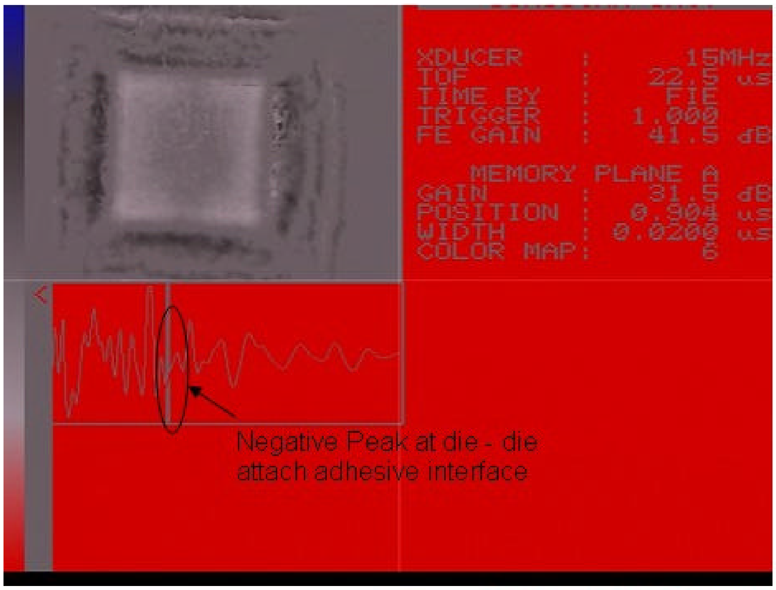
Table 6 – Post 3X Reflow Results

Component	**JEDEC MSL/ Tested MSL**	**Type of Failure**	**Number of Failures - Moisture Loading at JEDEC Levels and 3X Reflows**							
			Eutectic Tin/Lead				**Lead-free**			
			Low Peak Low Ramp	**Low Peak High Ramp**	**High Peak Low Ramp**	**High Peak High Ramp**	**Low Peak Low Ramp**	**Low Peak High Ramp**	**High Peak Low Ramp**	**High Peak High Ramp**
Optocouplers Black Overmold	2 / 3	Electrical Failure	0/16	0/16	0/16	**1/16**	0/16	0/16	0/16	**1/16**
Optocouplers Black Overmold	2 / 3	Mechanical Failure- Gel Squeeze	0/16	0/16	0/16	0/16	**9/16**	**12/16**	**15/16**	**16/16**
Optocouplers White Overmold	1 / 3	Electrical Failures	0/16	0/16	0/16	0/16	0/16	0/16	0/16	0/16
Plastic Quad Flat Pack (PQFP) Novalac Overmold	3/3	Die-Adhesive-Paddle Interface Delamination	Not tested	0/4	**1/4**	**1/4**	Not tested	Not tested	Not tested	Not tested
Plastic Leaded Chip Carrier (PLCC), Novalac Overmold	3/3	Die-Adhesive-Paddle Interface Delamination	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10
TSOPI Biphenyl Overmold	1 / 3	Die-Adhesive-Paddle Interface Delamination	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10
TSOP S, Novalac Overmold	4 / 4	Overmold - Die Interface	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10

Table 7 – Data Gate Shift Calculation for Acoustic Microscopy of Experimental Components

Component, Interface	Expected peak of waveform at the desired interface	Data gate shift Range (2*d/t), ms	Depth of Interface d, mm (Top of Die, Bottom of Die)
PQFP, Die-Die Attach	Negative Peak	(0.7068,0.9098)	≈ (1,0.4)
PLCC, Die-Die Attach	Negative Peak	(1.269,1.632)	≈ (1.55,0.4)
TSOP I, Die-Die Attach	Negative Peak	(0.20,0.251)	≈ (0.22,0.22)
TSOP S, Overmold-Die	Positive Peak	(0.233,0.304)	≈0.35

* Velocity of ultrasound in Epoxy $V_{Overmold}$ is 2.3-3.0 mm/µs
* Velocity of Ultrasound in Die $V_{Silicon}$ is 9.8mm/µs
* Gate Shift = 2*Distance to top of Die/$V_{Overmold}$ + 2*Thickness of Die/$V_{Silicon}$



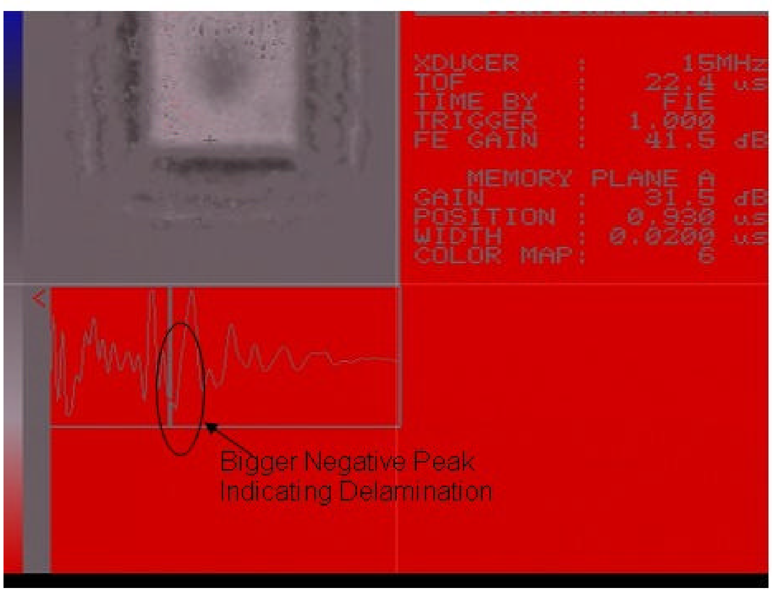


Figure 8 – A-Scan Images of a Good and a Delaminated PQFP

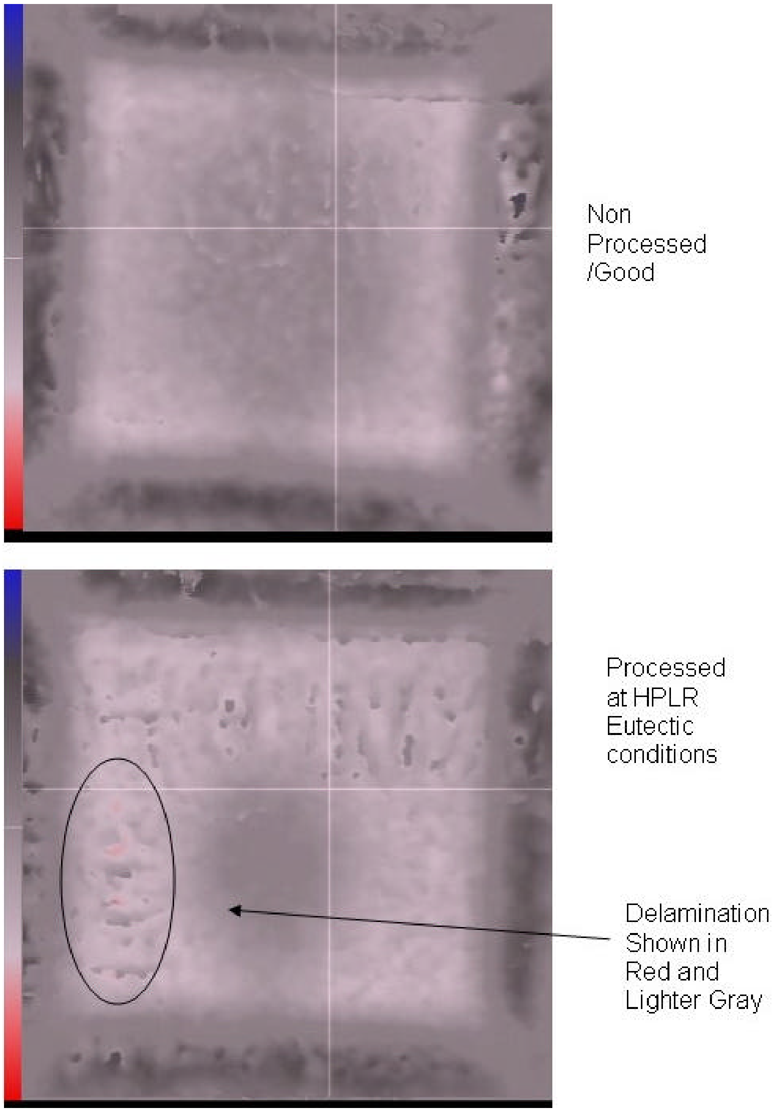


Figure 9 – CSAM Image of Good “Die-Die Attach” Interface and a Delaminated Interface

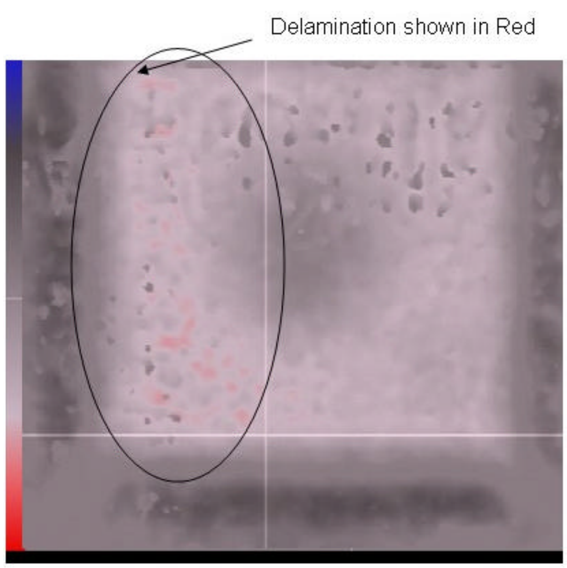


Figure 10 – C-SAM Image of a Delaminated “Die-Die Attach” Interface

Results and Inference

From the failure results, it is evident that preconditioning of most components based upon the floor life corresponding to their JEDEC classification and subsequent processing at different reflow conditions did not produce any component failures with the exception of optocoupler-B. Optocoupler-B produced an electrical defective at both eutectic and lead-free high peak, high ramp rate conditions. Mechanical failure such as gel squeeze was observed at all the lead-free conditions and the level of the defect depended upon the intensity of the reflow conditions. The failure, gel squeeze, was detected by visual inspection and is signified by the presence of white dried silicone, apparently squeezed out from the package. This was observed around the lead-plastic and plastic-plastic interface on the body of the optocoupler-B. Figure 11 shows the gel squeeze in an optocoupler-B processed at high peak and high ramp at lead-free conditions. An ANalysis Of VAriance (ANOVA) was performed for the mechanical failures (gel squeeze of the optocoupler-B) and the results are shown in Table 8. The analysis shows the significant effect of peak temperature at a confidence level of 95%. The effect of ramp up rate is significant at a confidence level of 90%. The main effects plot for the proportion of optocoupler-B defectives is shown in Figure 12. The interaction effects plot for the proportion of defectives is shown in Figure 13. From the graphs, it is evident that the effect of peak temperature is highly significant. The interaction effect of peak temperature and ramp up rate is more pronounced at temperatures corresponding to the lead-free reflow conditions.

The electrical failures of optocoupler-B were characterized using X-ray inspection to identify the failure mechanism. Figure 14 shows the delamination of the gallium arsenide die from the paddle surface. Consequently, it can be inferred that at high temperatures, the adhesion of the electrically conductive epoxy could is lessened due to a change in its physical properties. The optocoupler W, which is similar in construction to optocoupler-B, was subjected to similar preconditioning but did not fail in any of the test conditions. This is most likely due the white over mold material having superior reflow resistance compared to Novalac. In the case of Optocoupler B, the processing of components even at the de-rated conditions still produced failures. The other components, TSOP I and Optocoupler W, which were tested at de-rated conditions of MSL 3, from actual MSL of 1, did not produce any failure. In the case of the PLCC and the TSOP S parts that were tested at their corresponding JEDEC level of 3, no interface delamination and component damage was observed.

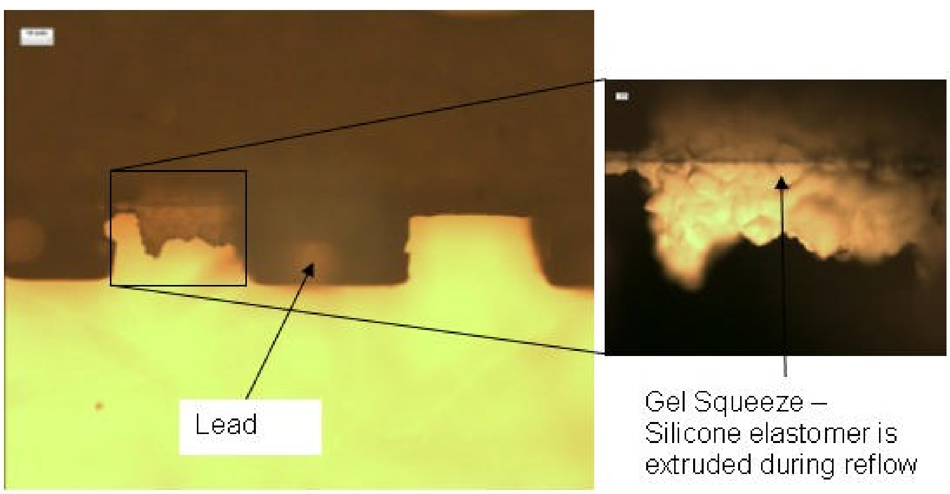


Figure 11 – Gel Squeeze in Optocoupler B

Table 8 – ANOVA Results for Optocoupler

Source	Degrees of Freedom DF	Seq SS	Adj SS	Adj MS	F	P
Peak Temperature	3	22.6875	22.6875	7.5625	132.34	0.000
Preheat Ramp Up Rate	1	0.125	0.125	0.1250	2.19	0.142
Peak Temperature* Preheat Ramp Up Rate	3	0.1875	0.1875	0.0625	1.09	0.355
Error	105	6	6	0.0571		
Total	127	30.8750				

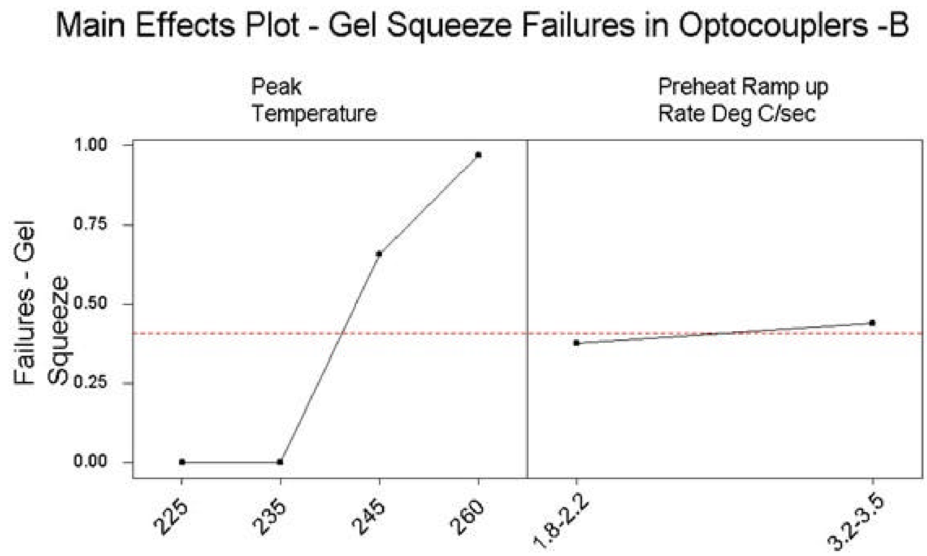


Figure 12 – Main Effects Plot for Optocoupler Gel Squeeze – Proportion Defective

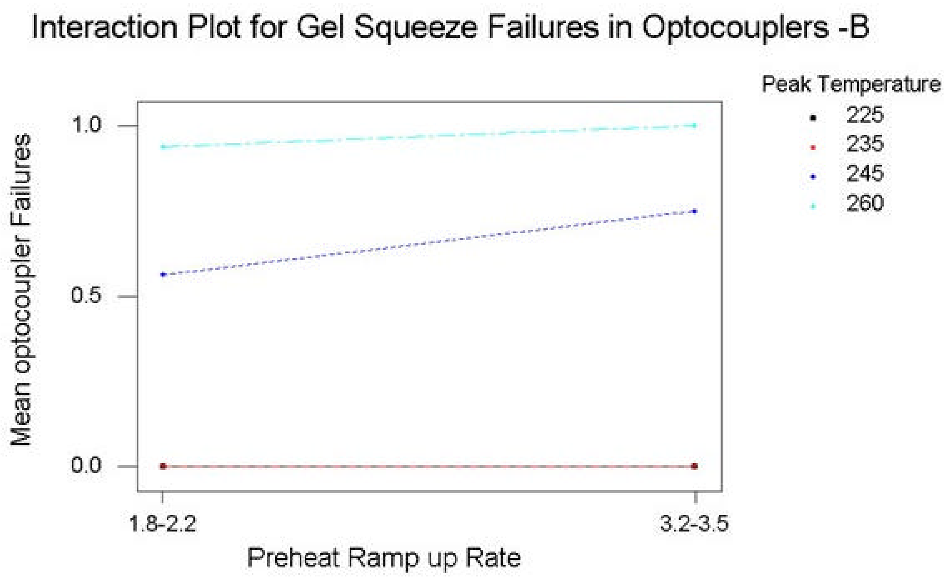


Figure 13 – Interaction Effects Plot for Optocoupler Gel Squeeze – Proportion Defectives

Figure 14 – Transmission X-ray Inspection Revealing die Delamination in Optocoupler B

Experiment Ii

Further experimentation was performed to investigate the effect on Optocoupler - B and Optocoupler – W at conditions corresponding to their JEDEC levels. The components were baked at 125 C for 24 hours and subjected to soak corresponding to their JEDEC MSL. The various JEDEC levels and soak requirements for the components are listed in Table 9. The components were subjected to the process conditions as listed in Table 2. The optocoupler - W was subjected to JEDEC levels, 1 and 2, to identify their effect on various types of failures (Mechanical and Electrical). The results and inference of the experiment are discussed below:

Table 9 – Moisture Load condition for Optocouplers and TSOP Packages

Component/Package	**Overmold Material**	**Experimental MSL**	**Soak Condition**	
			Time, Hours	**Conditions**
Optocoupler-B, SOIC	Novalac	1,2	168	≤ 85^{o}C/85% RH
Optocoupler-W, SOIC	White Molding Compound	1	168	≤85 ^{o}C/60% RH

Experiment Ii – Results And Inference

Analysis of Variance was performed for electrical and mechanical failures for Optocoupler B and W. The number of electrical and mechanical failures (Gel Squeeze) for the both optocouplers at various conditions is shown in Table 10 and Table 11. The results of electrical failure for optocoupler B are shown in Table 12. Based upon the ANOVA results, it is seen that the main effects of peak temperature and levels have a significant effect upon the number of electrical failures. From Figures 15 and 16, which are the main and interaction effects plots, it is seen that at lead free conditions (260C, 240C) there is a significant increase in electrical failures and there is a decrease in electrical failures with an increase (higher MSL treatment) in the level of conditioning. The ANOVA results for mechanical failure are shown in Table 13. Based upon the ANOVA results, the main effects of peak temperature have a significant effect on the gel squeeze failures. From Figure 17 and 18, it is seen that at lead free temperatures, the number of gel squeeze failures increases. Only one failure was observed for Optocoupler – W. The inferences from the experiment are as follows:

- The failures for Optocoupler B at levels 1 and 2 were higher than those obtained at level 3, which is consistent with a moisture root cause hypothesis.
- There was a significant amount of mechanical failures for optocouplers-B at both eutectic 63Sn/37Pb and lead free (SAC) reflow conditions and various moisture levels. The number of failures increases with increase in peak temperature.
- There was a significant amount of electrical and mechanical failures for optocouplers-B at lead free condition and various moisture levels. The number of failures increase with increase in peak temperature and preheat ramp rate from 1.8-2.2 C/S to 3.2-3.5C/S.

Table 10 – Number of Failures at Eutectic 63Sn/37Pb Conditions for Optocouplers

Component	**Type of Failure**	**Number of Failures - Moisture Loading at JEDEC Levels and 3X Reflows For Eutectic Tin/Lead**							
		Low Peak Low Ramp Level 1	**Low Peak Low Ramp Level 2**	**Low Peak High Ramp Level 1**	**Low Peak High Ramp Level 2**	**High Peak Low Ramp Level 1**	**High Peak Low Ramp Level 2**	**High Peak High Ramp Level 1**	**High Peak High Ramp Level 2**
Optocouplers Black Overmold	Electrical Failure	0/16	0/16	**1/16**	0/16	**1/16**	**1/16**	**3/16**	**1/16**
Optocouplers Black Overmold	Mechanical Failure-Gel Squeeze	0/16	0/16	0/16	0/16	**9/16**	**5/16**	**9/16**	**11/16**
Optocouplers White Overmold	Electrical Failures	0/16	0/16	0/16	0/16	0/16	0/16	0/16	0/16

Table 11 – Number of Failures at Lead Free Condition for Optocouplers

Component	Type of Failure	Number of Failures - Moisture Loading at JEDEC Levels and 3X Reflows For Lead Free							
		Low Peak Low Ramp Level 1	Low Peak Low Ramp Level 2	Low Peak High Ramp Level 1	Low Peak High Ramp Level 2	High Peak Low Ramp Level 1	High Peak Low Ramp Level 2	High Peak High Ramp Level 1	High Peak High Ramp Level 2
Optocouplers Black Overmold	Electrical Failure	**13/16**	**10/16**	**12/16**	**8/16**	**15/16**	**12/16**	**16/16**	**12/16**
Optocouplers Black Overmold	Mechanical Failure- Gel Squeeze	**13/16**	**14/16**	**14/16**	**15/16**	**16/16**	**15/16**	**16/16**	**16/16**
Optocouplers White Overmold	Electrical Failures	0/16	0/16	**1/16**	0/16	0/16	0/16	0/16	0/16

Table 12 – ANOVA Results of Electrical Failures in Optocoupler B

Source	Degrees Of Freedom DF	Seq SS	Adj SS	Adj MS	F	P
Peak Temperature (Temp)	3	37.6367	37.6367	12.5456	133.45	0
Preheat Ramp Rate (Ramp)	1	0.3164	0.3164	0.3164	3.37	0.068
Levels	1	0.0039	0.0039	0.0039	0.04	0.839
Temp*Ramp	3	0.3242	0.3242	0.1081	1.15	0.330
Temp*Levels	3	0.1367	0.1367	0.0456	0.48	0.693
Ramp*Levels	1	0.1914	0.1914	0.1914	2.04	0.155
Temp*Ramp*Levels	3	0.3867	0.3867	0.1289	1.37	0.252
Error	240	22.5625	22.5625	0.094		
Total	255	61.5586				

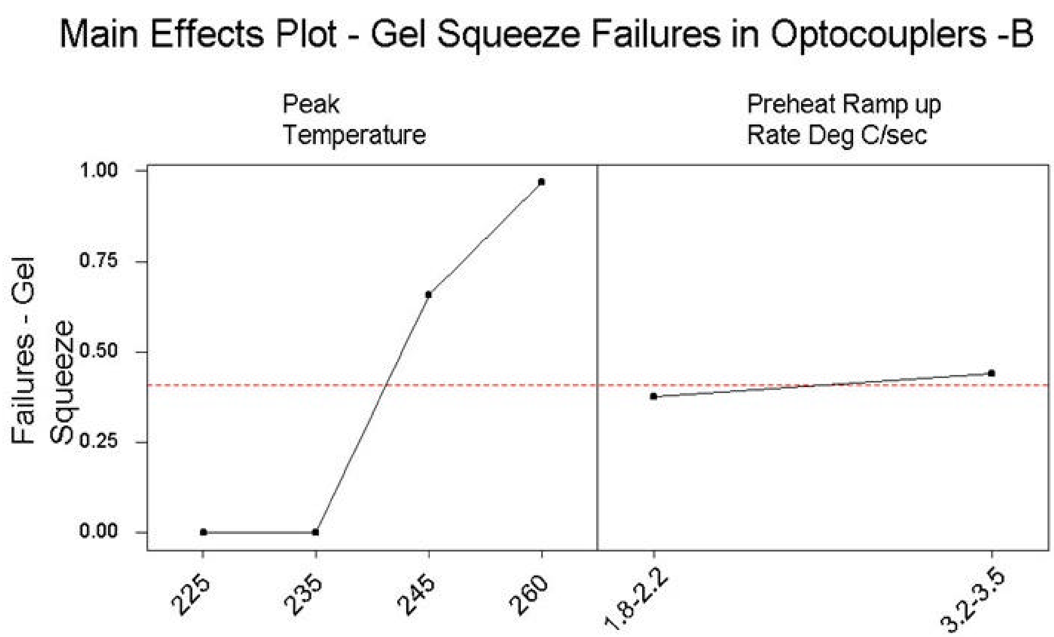


Figure 15 – Main Effects Plot for Optocoupler B Electrical Failures – Proportion Defective

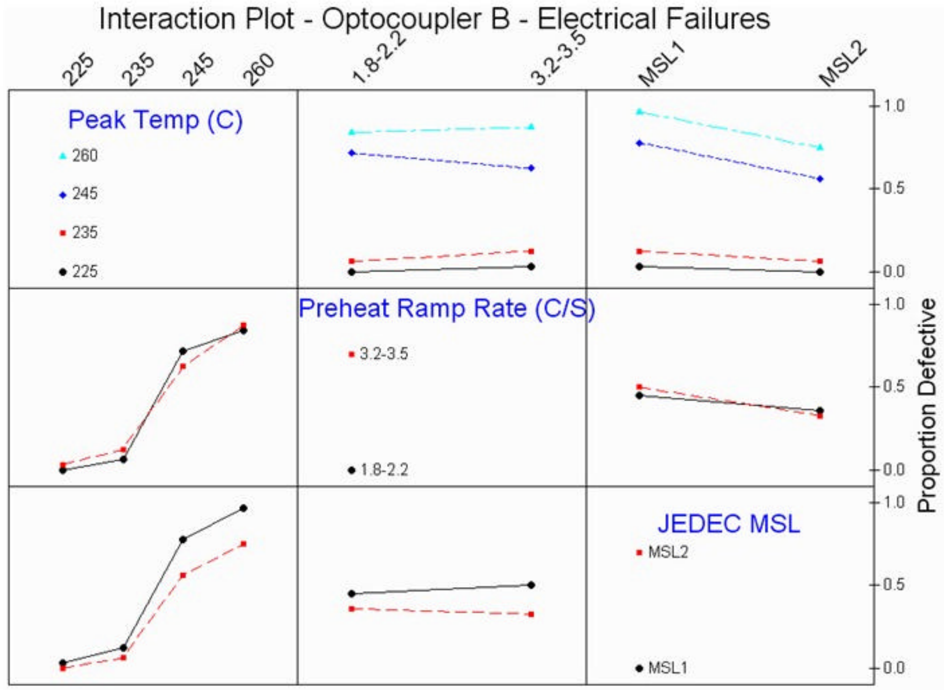


Figure 16 – Interaction Effects Plot for Optocoupler B Electrical Failures – Proportion Defective

Table 13 – ANOVA Results of Mechanical Failures in Optocoupler B

Source	Degrees of Freedom DF	Seq SS	Adj SS	Adj MS	F	P
Peak Temperature (Temp)	3	33.668	33.668	11.2227	102.36	0
Preheat Ramp Rate (Ramp)	1	0.0039	0.0039	0.0039	0.04	0.850
Levels	1	1.1289	1.1289	1.1289	10.30	0.002
Temp*Ramp	3	0.2305	0.2305	0.0768	0.70	0.552
Temp*Levels	3	0.4805	0.4805	0.1602	1.46	0.226
Ramp*Levels	1	0.0977	0.0977	0.0977	0.89	0.346
Temp*Ramp*Levels	3	0.0117	0.0117	0.0039	0.04	0.991
Error	240	26.3125	26.3125	0.1096		
Total	255	61.9336				

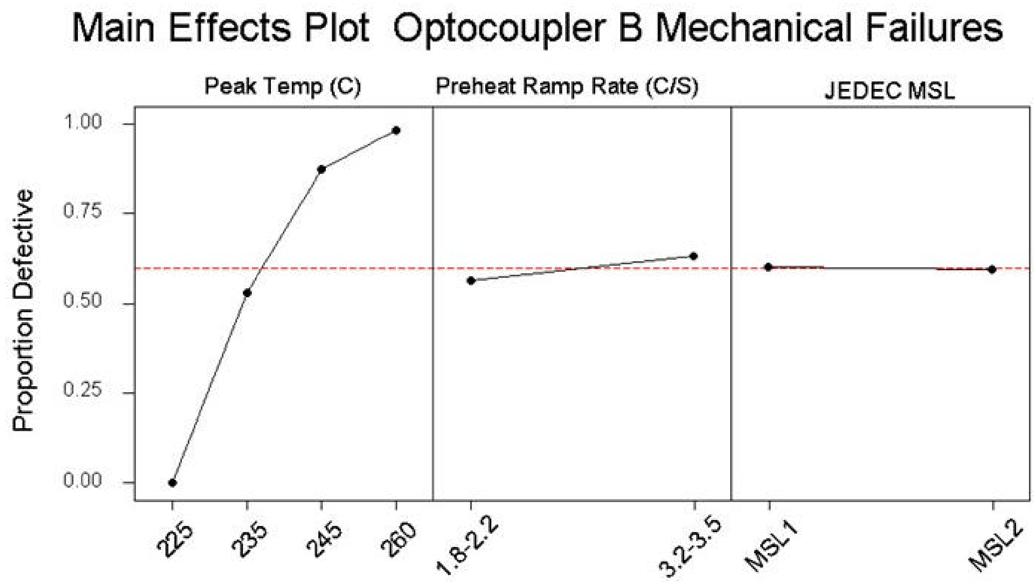


Figure 17 – Main Effects Plot for Optocoupler B Mechanical

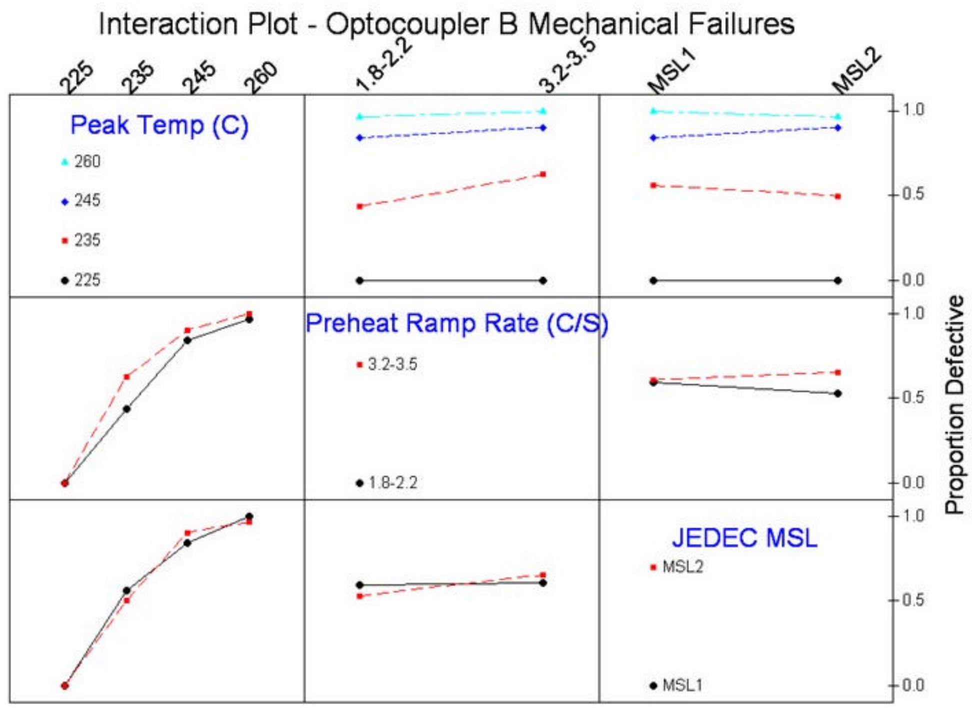


Figure 18 – Interaction Effects Plot for Optocoupler B Electrical Failures – Proportion Defective

Conclusion

The objective of the experiment was to observe the vulnerability of the components at both eutectic and lead-free conditions. The reflow damage was characterized on moisture absorbed plastic over molded components at eutectic and lead free temperature conditions. The components were moisture loaded for different times at 30°C/60% RH. The PLCC and TSOP components did not produce any delamination of the observed interface at their corresponding JEDEC MSL of 3 and easily withstood the effect of moisture and both eutectic and lead free reflow at the tested conditions. The PQFP that was tested only at the eutectic reflow conditions, produced delaminations at an average high peak temperature of 235°C. Optocoupler W, Optocoupler B and TSOP I were subjected to a de-rated preconditioning and reflowed at different conditions. The lower level of preconditioning (MSL 3) still produced failures in the case of optocoupler B which has a MSL 2 rating. This indicates that this component is not compatible with lead-free reflow soldering when the MSL is de-rated to one higher (from MSL 2 to MSL 3) level. The fact that Optocoupler W and TSOP I, both classified as MSL 1 components, did not fail at de-rated preconditioning and processing might lead to the conclusion that de-rating helped these components' performance. To support this inference, significant failures were observed for the optocoupler Bs when they were processed at their (lower) JEDEC levels. Also, de-rating the component's MSL alone may not be the solution for transition to lead free assembly. This was evident in the case of Optocoupler B that produced failures at a JEDEC level higher (MSL 3) than its qualified moisture sensitivity classification (MSL 2). Approximately, one out of three components subjected to JEDEC MSL and de-rated JEDEC MSL failed at harsher reflow conditions. Both the peak reflow temperature and preheat ramp up rate were found to be significant factors for mechanical damage at ? =.1. De-rating the MSL moisture loading form MSL 2 to MSL 3 was found to be ineffective in preventing the post reflow failures of the optocoupler B components. The inability of such components to withstand the rigorous reflow conditions of lead free temperatures was demonstrated in this experiment.

This study on moisture and reflow sensitivity of the plastic encapsulated SMT packages was focused on understanding the ability of such packages to withstand rigorous reflow conditions. The peak reflow temperature was identified as being the most significant factor affecting the robustness of the component, followed by the preheat ramp up rate which also affected performance to a lesser degree. The results of the experiments reveal the vulnerability of components like the optocoupler at lead free reflow conditions. The research emphasized the inability of certain plastic SMT devices to pass at the tested moisture and reflow conditions. Two other packages, both classified as MSL 1 components, did not fail derated two levels to MSL 3 preconditioning, but raising the MSL of a component by two levels is an unacceptable solution for most component users (assembly plants), and thus most component manufacturers.. There would be a large increase in work load to store, track and re-dry so many of high moisture sensitivity Consequently, solely de-rating the component's MSL, to meet stringent package handling requirements, is not a certain solution to transition into led free assembly. This was evident in the case of optocoupler package that produced failures even when tested at a higher JEDEC level (MSL 3), translating to less moisture exposure than its 63Sn/37Pb qualified moisture sensitivity classification (MSL 2). Transition to lead free processing requires either component specific JEDEC MSL re-qualification or significant improvements in material properties for the components to survive reflow, which would still result in MSL re-qualification at lead free temperatures.

References

1. Feng, Y., Raju, V.R., and Suhir. E., "Moisture Induced Failures of Plastic Packages of IC Devices State-of-the-Art and Crucial Needs", Structural Analysis in Microelectronics and Fiber Optics, Vol. 21, 1997, pp. 89-139.
2. Prud'homme, M., "Ambient Moisture Characterization of Thin Small Outline Packages (TSOPs)", Proceedings - IEEE International Reliability Physics Symposium, Piscataway, NJ, Vol. 32, 1994, pp. 79-86.
3. Cho, T., Lee, K., Lee, M., Ahn, S., and Oh, S., "An Improvement in Reflow Performance of Plastic Packages", Proceedings - IEEE Electronics Components and Technology Conference, Orlando, FL, 1996, pp. 931-935.
4. Standards for Handling, Packing, Shipping and Use of Moisture/Reflow Sensitive Surface Mount Devices, IPC/JEDEC Standards J-STD-033, 1999.
5. Anson, S. J., "Failure Analysis Techniques for Area Array Packages", Proceedings – APEX, San Diego, CA, 1999, pp. 232-238.
6. Huang, B., and Lee, N. C., "Prospect of Lead-free Alternatives for Reflow Soldering", Proceedings - APEX, San Diego, CA, 1999, pp.1- 11.
7. Moisture/Reflow Sensitivity Classification for Nonhermetic Solid State Surface Mount Devices, IPC/JEDEC Standards J-STD-020A, 1999.
8. Kitano, M., Nishimura, A., Kawai, S., and Nishi, K., "Analysis of Package Cracking During Reflow Soldering Process", Proceedings – 26th International Reliability Physics Symposium, 1988, pp. 90-95.
9. Mei, Y, H., and Liu, S., "An Investigation to Popcorning Mechanisms for IC Plastic Packages: Defect Initiation", Application of Fracture Mechanics in Electronics Packaging and Materials, ASME 1995, Vol. 11, pp. 85-97.
10. Maggi, I., "Control of Moisture Absorption by SMD Packages", Technical Paper, SGS - Thompson Microelectronics, Malta, 2000.
11. Barber, J., "Plastic Packaging and the Effects of Surface Mount Soldering Techniques", Technical Paper, Microchip Technology Inc., Hauppauge, NY, 1995.
12. Anson, S. J., "Quick Reference Guide for Scanning Acoustic Microscopy", Personal Correspondence, IBM Microelectronics, Endicott, NY, 2002.
13. Tanaka, N., Kitano, M., Kumuzawa, T., and Nishimura, A., "Evaluation of Interface Delamination in IC Packages by Considering Swelling of the Molding Compound due to Moisture Absorption", Proceedings – IEEE Electronics Components and Technology Conference, San Jose, CA, 1997, pp. 84-90.

Moisture and Reflow Sensitivity Evaluations of SMT Packages as a Function of Reflow Profile at Eutectic and Lead Free Temperatures

Session: Assembly Reflow
Wed. 2/25/04 8:00-9:30 AM

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All research was conducted at Endicott Interconnect Technologies, Inc.

Overview

- Moisture sensitivity
- Lead free solder temperatures
- Components studied
- Reflow parameters
- Screening DOE
  - Results
    - Optocoupler B
    - PQFP
- Optocoupler B DOE 2
- Conclusions

Moisture Sensitivity

• Component damage is caused by absorbed moisture becoming rapidly vaporized during reflow.

• Vapor builds an internal pressure resulting in popcorn delamination.

• Damage can be internal electrical or external mechanical damage such as cracks.

Moisture Sensitivity - JEDEC Levels

July 2002 IPC/JEDEC J-STD-020B

Table 5-1 Moisture Sensitivity Levels

LEVEL	FLOOR LIFE		SOAK REQUIREMENTS			
			STANDARD		ACCELERATED EQUIVALENT [1]	
	TIME	CONDITIONS	TIME (hours)	CONDITIONS	TIME (hours)	CONDITIONS
1	Unlimited	≤30°C/85% RH	168 +5/-0	85°C/85% RH		
2	1 year	≤30°C/60% RH	168 +5/-0	85°C/60% RH		
2a	4 weeks	≤30°C/60% RH	696[2] +5/-0	30°C/60% RH	120 +1/-0	60°C/60% RH
3	168 hours	≤30°C/60% RH	192[2] +5/-0	30°C/60% RH	40 +1/-0	60°C/60% RH
4	72 hours	≤30°C/60% RH	96[2] +2/-0	30°C/60% RH	20 +0.5/-0	60°C/60% RH
5	48 hours	≤30°C/60% RH	72[2] +2/-0	30°C/60% RH	15 +0.5/-0	60°C/60% RH
5a	24 hours	≤30°C/60% RH	48[2] +2/-0	30°C/60% RH	10 +0.5/-0	60°C/60% RH
6	Time on Label (TOL)	≤30°C/60% RH	TOL	30°C/60% RH		

Note 1: **CAUTION** – The "accelerated equivalent" soak requirements shall not be used until correlation of damage response, including electrical, after soak and reflow is established with the "standard" soak requirements or if the known activation energy for diffusion is 0.4 - 0.48 eV. Accelerated soak times may vary due to material properties, e.g., mold compound, encapsulant, etc. JEDEC document JESD22-A120 provides a method for determining the diffusion coefficient.

Source: IPC/JEDEC J-STD-020B, July 2002

Typical Reflow Temperatures

Alloy	63Sn/37Pb	Lead Free (SAC)
Melting Temp	183 ^{o}C	217 - 221 ^{o}C
Component Temp	220 - 240 ^{o}C	235 - 260 ^{o}C

Moisture Sensitivity

- Component moisture sensitivity is a challenge with 63Sn/37Pb.

- Impending lead free conversion and associated 34-38 C higher melting temperatures (SAC) will lead to higher reflow temperatures.

- Likelihood of moisture induced damage will increase with lead free solders.

- Can current moisture sensitive components handle the higher reflow temperatures at the current MSLs, and if not, can we simply de-rate by one MSL such as from MSL 2 to MSL 3?

Moisture Sensitivity - JEDEC Levels

Table 4-1 Package Peak Reflow Temperatures

Reflow Conditions	Pkg. Thickness ≥2.5 mm or Pkg. Volume ≥350 mm^3	Pkg. Thickness <2.5 mm and Pkg. Volume <350 mm^3
SnPb Eutectic	Convection 225 +0/-5°C	Convection 240 +0/-5°C
Pb Free	Convection 245 +0/-5°C	Convection 250 +0/-5°C

Note 1: Package volume excludes external terminals (balls, bumps, lands, leads) and or nonintegral heat sinks.

Note 2: The maximum component temperature reached during reflow depends on package thickness and volume. The use of convection reflow processes reduces the thermal gradients between packages. However, thermal gradients due to differences in thermal mass of SMD packages may still exist.

Note 3: Components intended for use in a "lead-free" assembly process shall be evaluated using the "lead free" peak temperature and profiles defined in Tables 4-1 and 5-2 whether or not lead free.

Note 4: It is possible that very large (≥1400 cm^2) thick (≥2.5 mm) boards that use components with a wide range of thermal mass, and/or boards undergoing rework, might have difficulty maintaining all component bodies below the maximum temperatures in this specification. In such cases, the MSL level must be determined for the body temperature the component will attain.

Source: IPC/JEDEC J-STD-020B, July 2002

Components Studied

Component/ Package	Overmold Material	JEDEC MSL	Floor Life	
			Time, Hours	**JEDEC Conditions**
Optocoupler-B, SOIC	Novalac	2	1 Year	≤30 ^{o}C/60% RH
Optocoupler-W, SOIC	White Molding Compound	1	Unlimited	≤30 ^{o}C/85% RH
PLCC	Novalac	3	168	≤30 ^{o}C/60% RH
TSOP-S	Novalac	3	168	≤30 ^{o}C/60% RH
TSOP-I	Biphenyl	1	Unlimited	≤30 ^{o}C/60% RH
PQFP	Novalac	4	72	≤30 ^{o}C/60% RH

Screening DOE

The original plan was to analyze each component as an individual DOE.

A reflow test matrix was run on all 6 components studied.

Preheat Ramp Rate is measured as the maximum slope from room temperature to120C

Reflow Matrix - Screening DOE

Factors	Reflow Peak Temperature	Preheat Ramp Rate
	225+/-5^{o}C	1.8 -2.2^{o}C/Sec
	235+/ 5^{o}C	3.2-3.5^{o}C/Sec
	245+/-3^{o}C	
	260+/-3^{o}C	
Levels	**4**	**2**
Response Variables	Varied for each component. Could be, 1) Electrical Function 2) Mechanical Integrity (0 = no cracks or gel squeeze, 1= visible damage) 3) Presence of delamination – measured with acoustic microscopy	
Replicates	Varied for each component	

Screening DOE(S) Results

Component	JEDEC MSL/ Tested MSL	Type of Failure	Number of Failures - Moisture Loading at JEDEC Levels and 3X Reflows							
			Eutectic Tin/Lead				Lead-free			
			Low Peak Low Ramp	Low Peak High Ramp	High Peak Low Ramp	High Peak High Ramp	Low Peak Low Ramp	Low Peak High Ramp	High Peak Low Ramp	High Peak High Ramp
Optocouplers Black Overmold	2 / 3	Electrical Failure	0/16	0/16	0/16	**1/16**	0/16	0/16	0/16	**1/16**
Optocouplers Black Overmold	2 / 3	Mechanical Failure- Gel Squeeze	0/16	0/16	0/16	0/16	**9/16**	**12/16**	**15/16**	**16/16**
Optocouplers White Overmold	1 / 3	Electrical Failures	0/16	0/16	0/16	0/16	0/16	0/16	0/16	0/16
Plastic Quad Flat Pack (PQFP) Novalac Overmold	3 / 3	Die-Adhesive-Paddle Interface Delamination	Not tested – limited samples	0/4	**1/4**	**1/4**	Not tested	Not tested	Not tested	Not tested
Plastic Leaded Chip Carrier (PLCC), Novalac Overmold	3 / 3	Die-Adhesive-Paddle Interface Delamination	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10
TSOPI Biphenyl Overmold	1 / 3	Die-Adhesive-Paddle Interface Delamination	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10
TSOP S, Novalac Overmold	4 / 4	Overmold - Die Interface	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10

Screening DOE(S) Summary

Component	**JEDEC MSL/ Tested MSL**	**Type of Failure**	**Number of Failures - Moisture Loading at JEDEC Levels and 3X Reflows**
Optocouplers Black Overmold	2 / 3	Electrical Failure	1/16 defective at eutectic high peak and high ramp, and 1/16 at lead free high peak high ramp
Optocouplers Black Overmold	2 / 3	Mechanical Failure- Gel Squeeze	52/64 components defective at lead free temps
Optocouplers White Overmold	1 / 3	Electrical Failures	No defects
Plastic Quad Flat Pack (PQFP) Novalac Overmold	3 / 3	Die-Adhesive- Paddle Interface Delamination	High Peak (Eutectic) caused 2/8 components to be defective, where as the were 0/4 low peak (eutectic) defects
Plastic Leaded Chip Carrier (PLCC), Novalac Overmold	3 / 3	Die-Adhesive- Paddle Interface Delamination	No defects (0/80)
TSOPI Biphenyl Overmold	1 / 3	Die-Adhesive- Paddle Interface Delamination	No defects (0/80)
TSOP S, Novalac Overmold	4 / 4	Overmold - Die Interface	No defects (0/80)

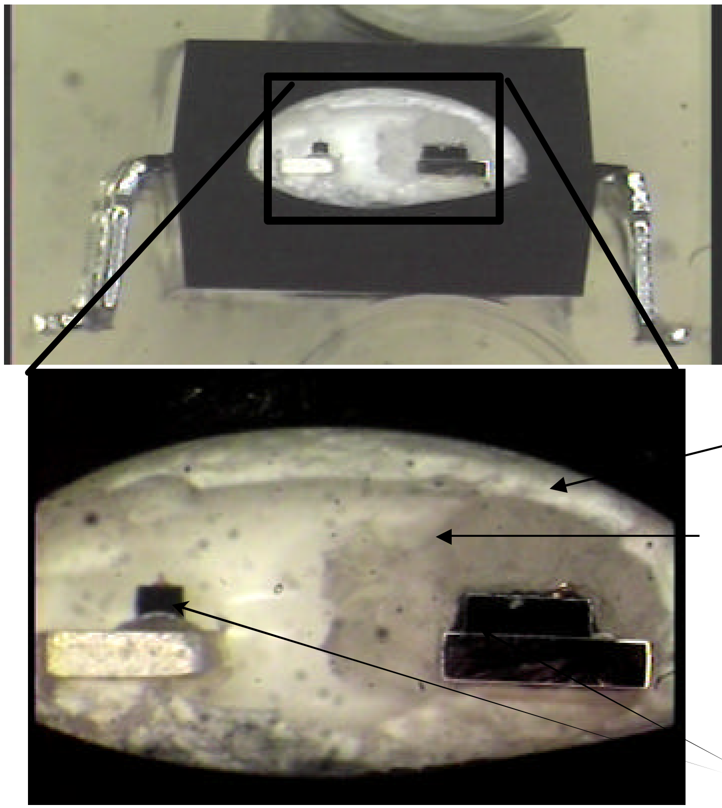
Screening DOE Summary

Two components had defects:

1) Optocoupler B (electrical and mechanical defects)

2) PQFP (delamination deselected by acoustic microscopy)

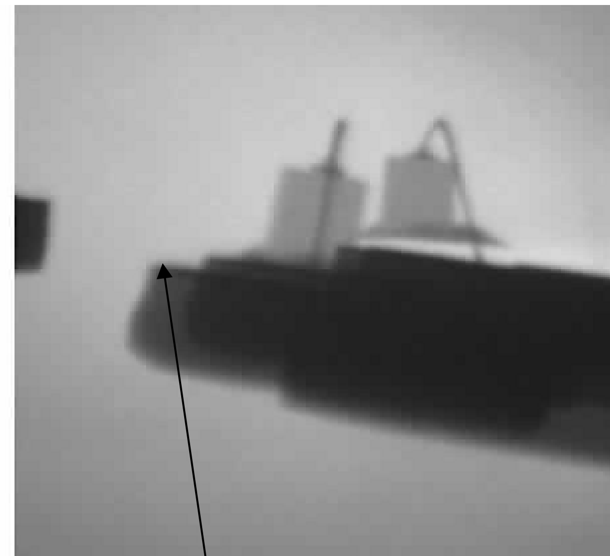
Optocoupler B Construction



Reflector
(White)

Silicone
(Translucent
Light Pipe)

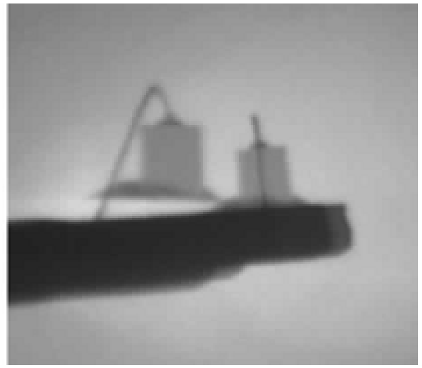
Die

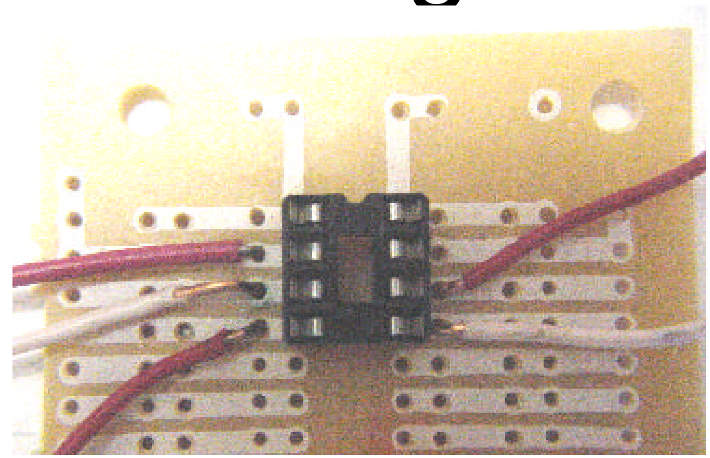


Ga/As emitter die lifts off
lead frame due to moisture
out gassing during reflow

Optocoupler B Testing

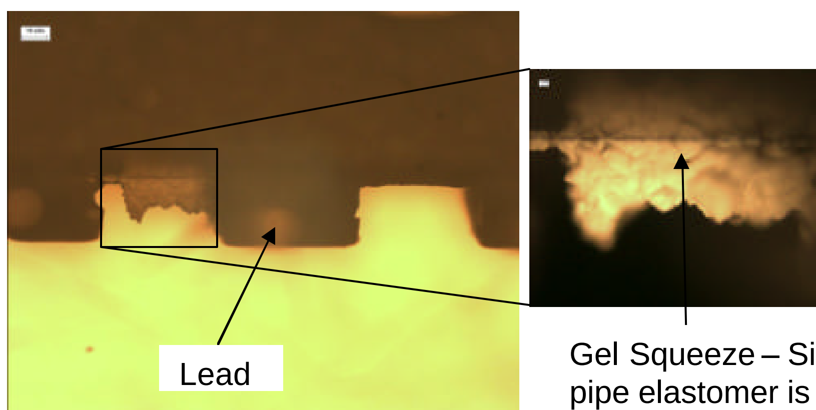
Electrical
Failure Mode





Electrical Test Board – Checks for voltage dependent continuity

Mechanical
Failure Mode

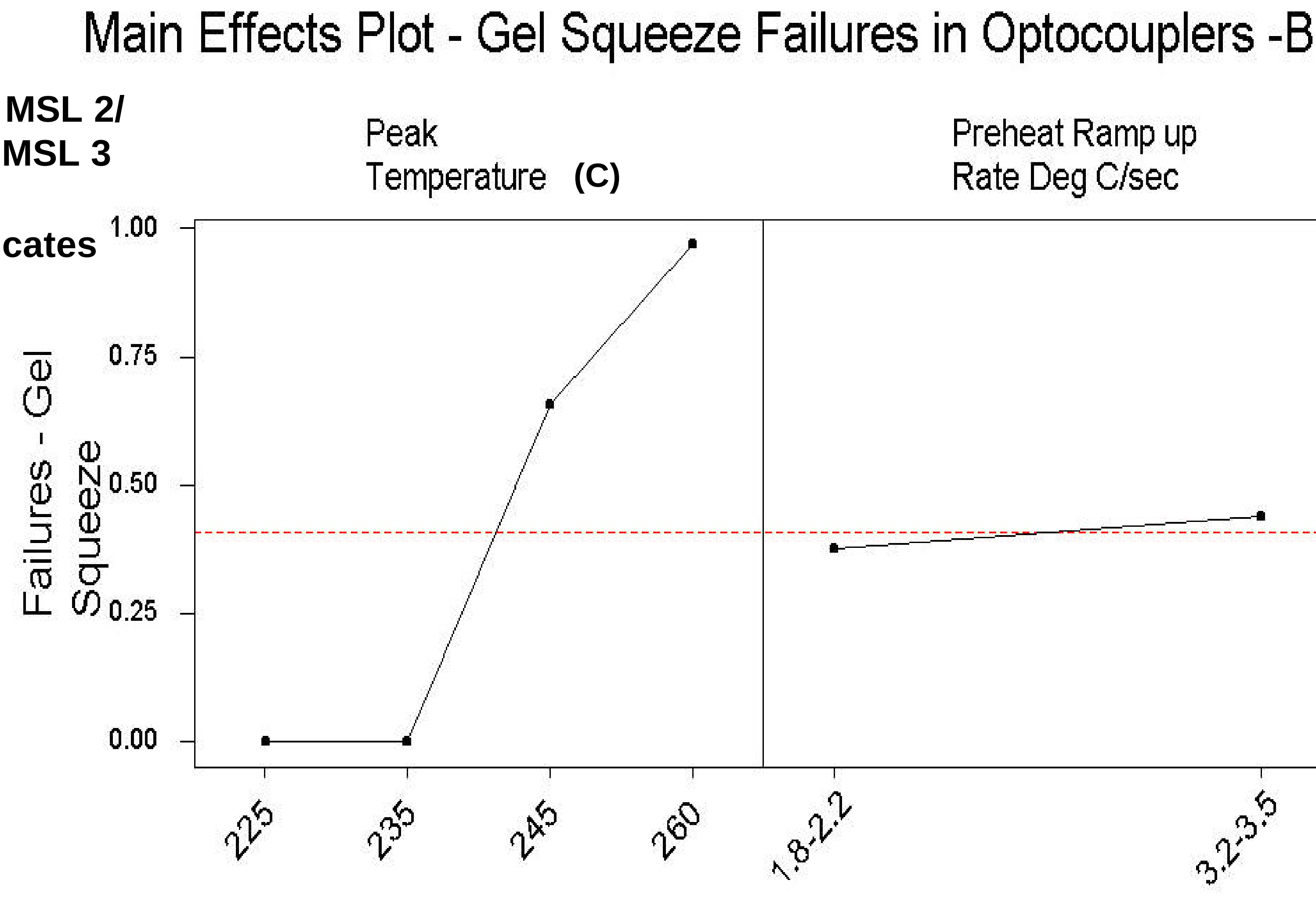


Gel Squeeze – Silicone light pipe elastomer is extruded during reflow

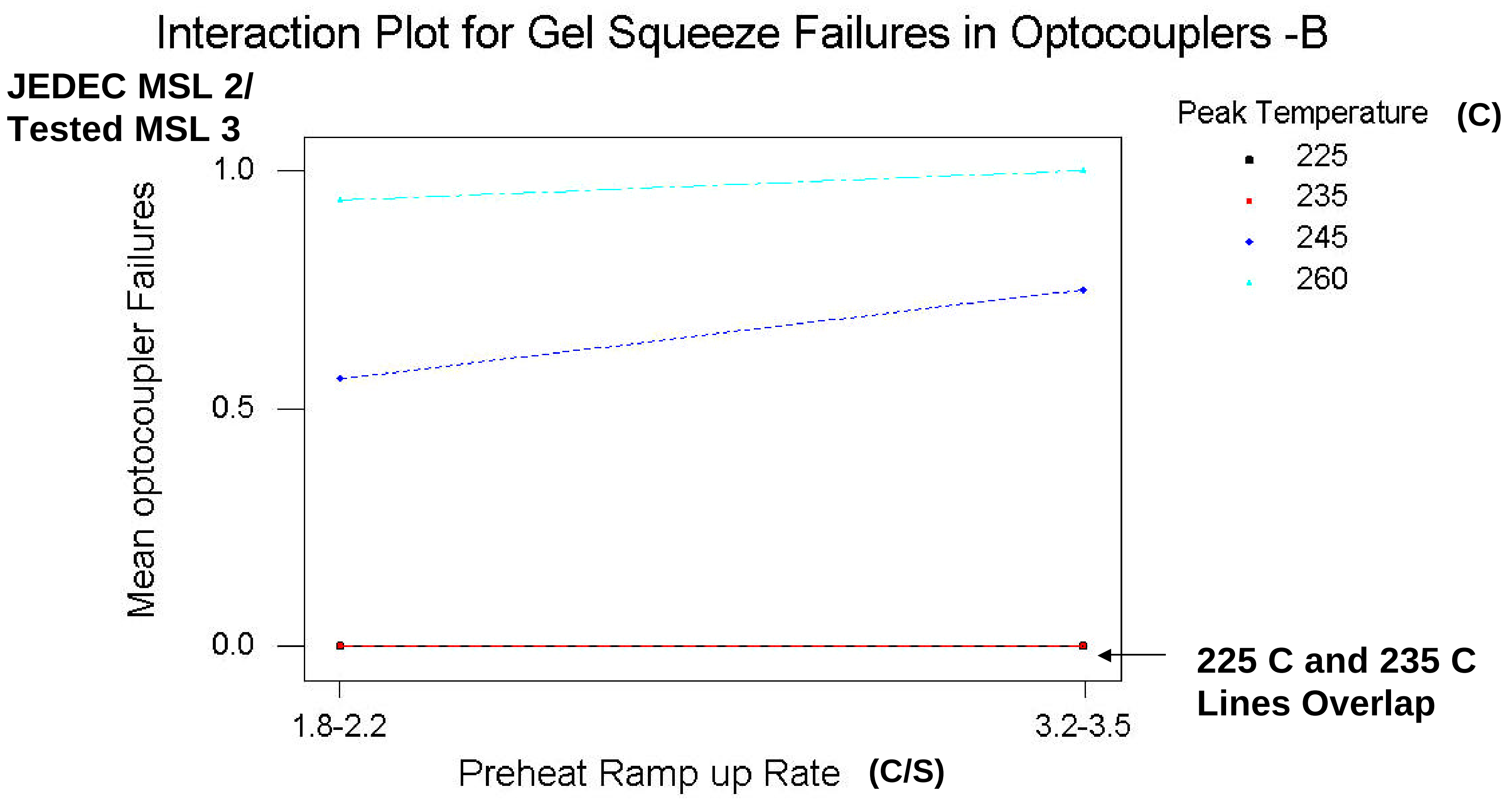
Optocoupler B
Mechanical Failure ANOVA

JEDEC MSL 2/
Tested MSL 3

16 replicates



Optocoupler B
Mechanical Failure ANOVA

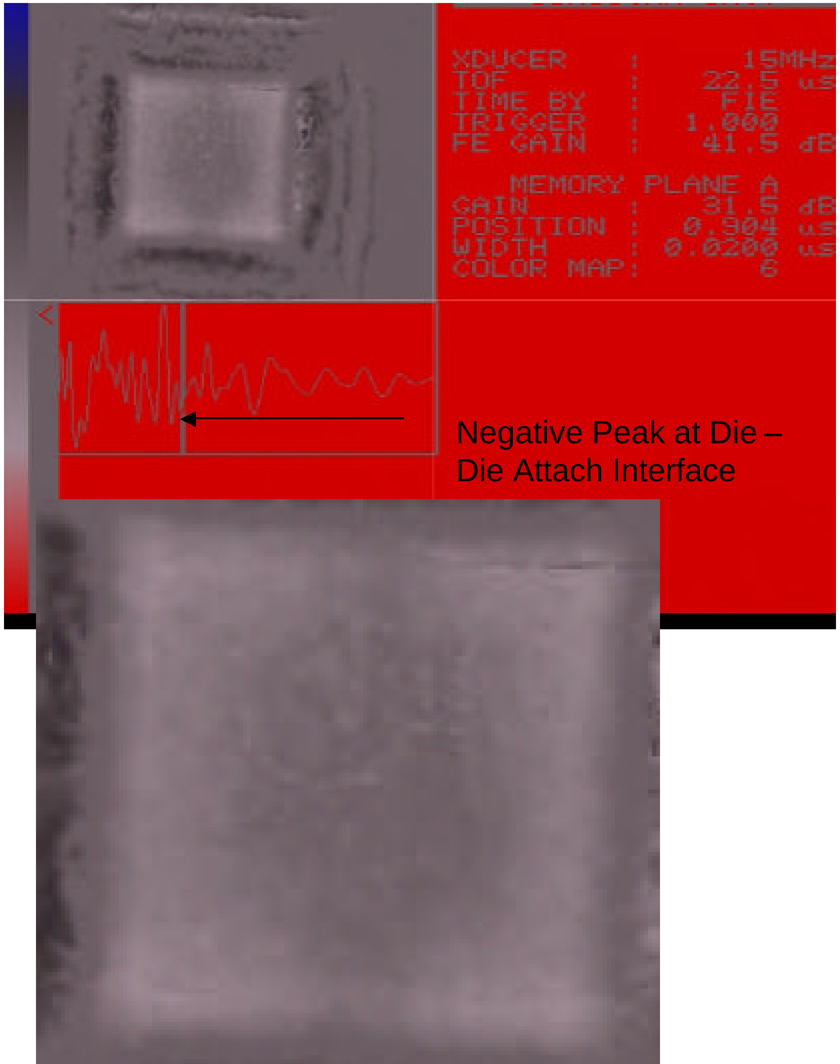


Optocoupler B Mechanical Failure ANOVA

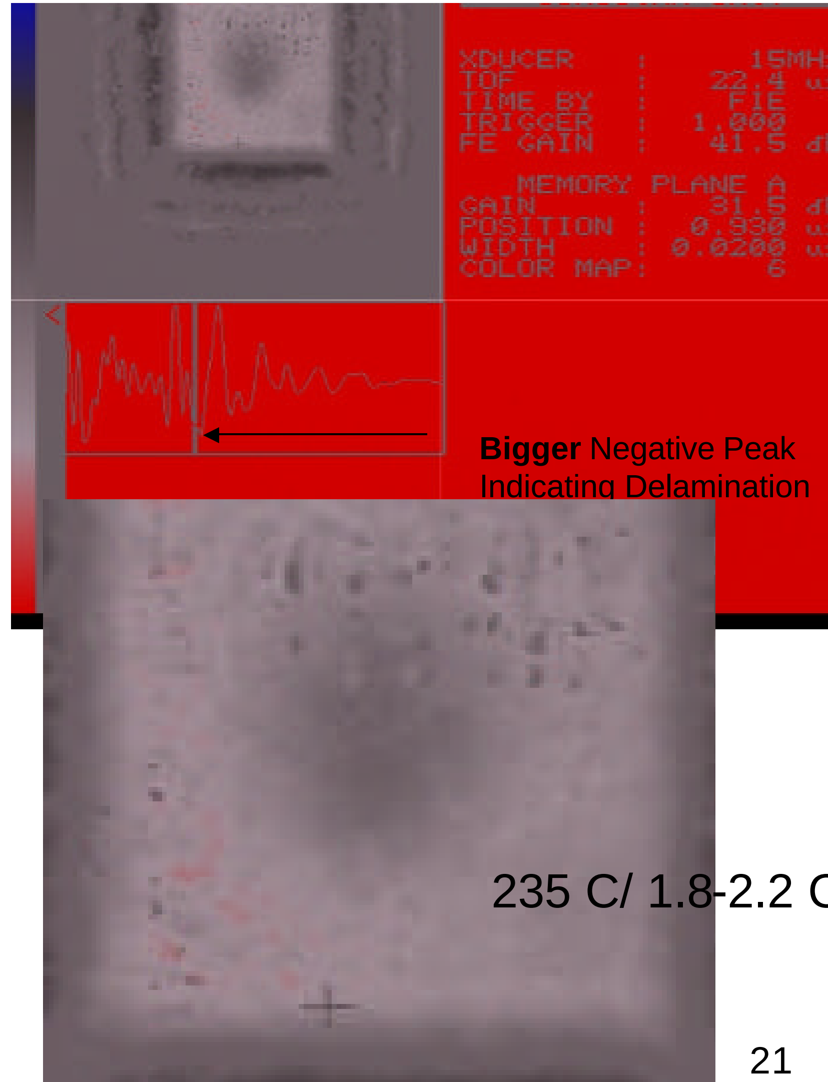
Source	**Degrees of Freedom**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
Peak Temperature	3	22.6875	22.6875	7.5625	132.34	0.000
Preheat Ramp Up Rate	1	0.1250	0.1250	0.1250	2.19	0.142
Peak Temperature* Preheat Ramp Up Rate	3	0.1875	0.1875	0.0625	1.09	0.355
Error	105	6	6	0.0571		
Total	127	30.8750				

PQFP Defects

PQFP Defects



Good Component



235 C/ 1.8-2.2 C/S

Delaminated Component

PQFP Results

Component	JEDEC MSL/ Tested MSL	Type of Failure	Number of Failures - Moisture Loading at JEDEC Levels and 3X Reflows							
			Eutectic Tin/Lead				Lead-free			
			Low Peak Low Ramp	**Low Peak High Ramp**	**High Peak Low Ramp**	**High Peak High Ramp**	**Low Peak Low Ramp**	**Low Peak High Ramp**	**High Peak Low Ramp**	**High Peak High Ramp**
Plastic Quad Flat Pack (PQFP) Novalac Overmold	3 / 3	Die-Adhesive-Paddle Interface Delamination	Not tested – limited samples	0/4	**1/4**	**1/4**	Not tested	Not tested	Not tested	Not tested

Due to limited parts a full DOE matrix was not run.

Two failures occurred at the eutectic high peak temp (235 C).

This suggests that high peak temperature promotes component damage as measured by acoustic microscopy.

Optocoupler B DOE 2

Optocoupler B DOE 2

DOE 2 was conducted on the Optocoupler B at the qualified JEDEC Level of 2 and also at JEDEC level 1.

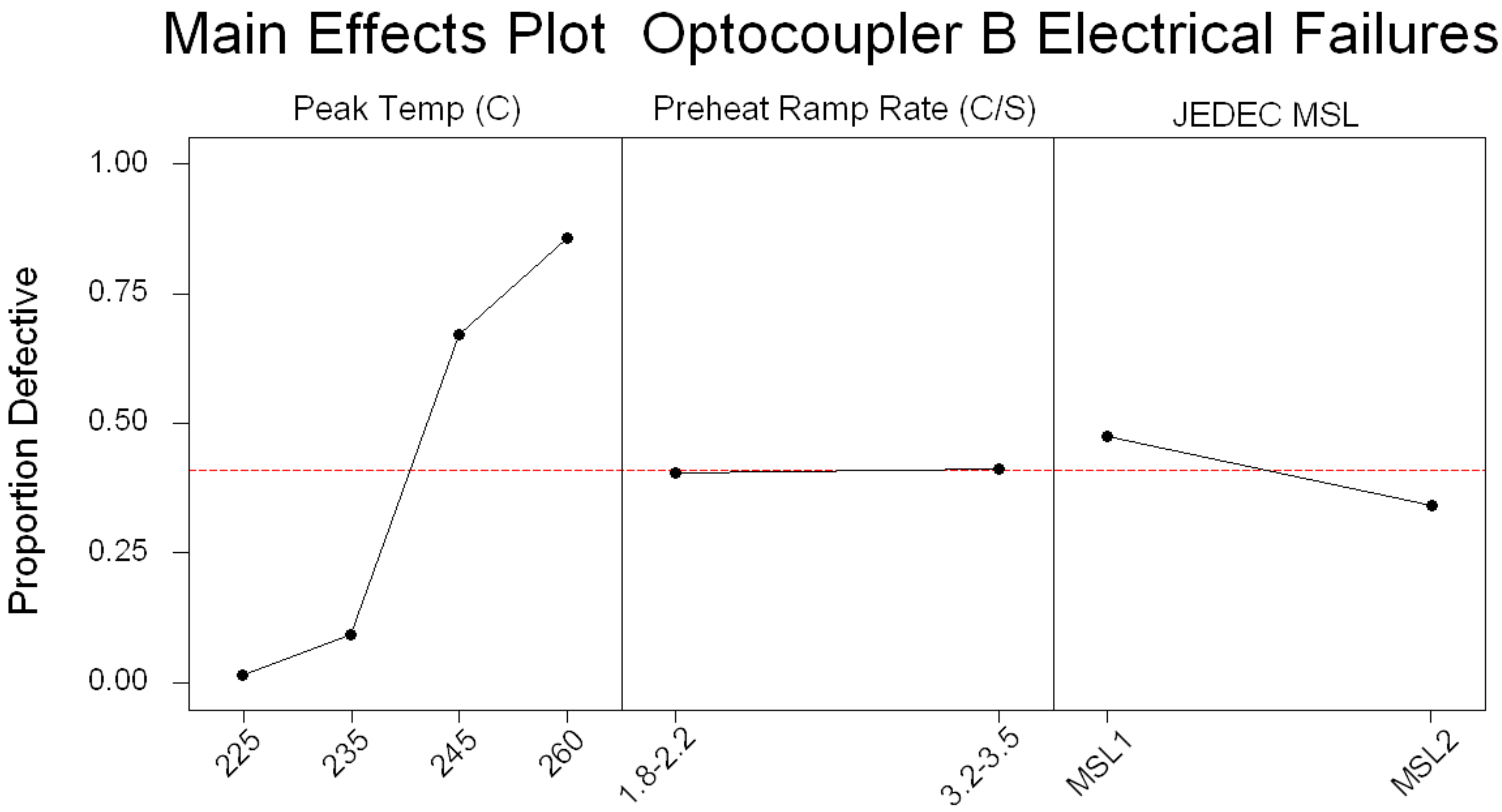
Factors	Reflow Peak Temperature	Preheat Ramp Rate	JEDEC Level
	225+/-5^{o}C	1.8 -2.2^{o}C/Sec	1
	235+/ 5^{o}C	3.2-3.5^{o}C/Sec	2
	245+/-3^{o}C		
	260+/-3^{o}C		
Levels	**4**	**2**	**2**
Response Variables	1) Electrical function 2) Mechanical Integrity (0 = no cracks or gel squeeze, 1= visible damage)		
Replicates	16		

Optocoupler B DOE 2

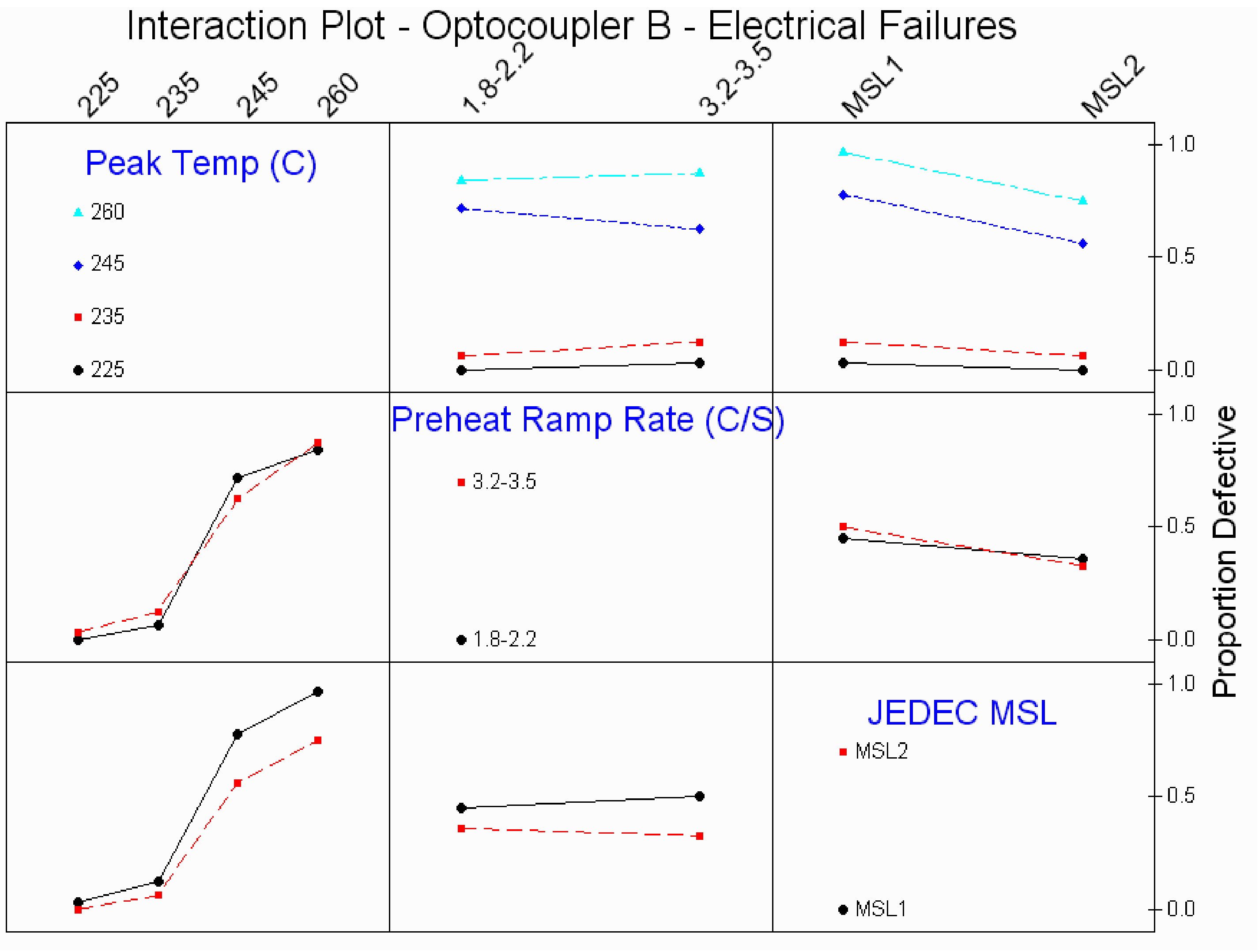
Component	Type of Failure	Number of Failures - Moisture Loading at JEDEC Levels and 3X Reflows For **Eutectic Tin/Lead**							
		Low Peak Low Ramp Level 1	Low Peak Low Ramp Level 2	Low Peak High Ramp Level 1	Low Peak High Ramp Level 2	High Peak Low Ramp Level 1	High Peak Low Ramp Level 2	High Peak High Ramp Level 1	High Peak High Ramp Level 2
Optocouplers Black Overmold	Electrical Failure	0/16	0/16	1/16	0/16	1/16	1/16	3/16	1/16
Optocouplers Black Overmold	Mechanical Failure-Gel Squeeze	0/16	0/16	0/16	0/16	9/16	5/16	9/16	11/16

Component	Type of Failure	Number of Failures - Moisture Loading at JEDEC Levels and 3X Reflows For **Lead Free**							
		Low Peak Low Ramp Level 1	Low Peak Low Ramp Level 2	Low Peak High Ramp Level 1	Low Peak High Ramp Level 2	High Peak Low Ramp Level 1	High Peak Low Ramp Level 2	High Peak High Ramp Level 1	High Peak High Ramp Level 2
Optocouplers Black Overmold	Electrical Failure	13/16	10/16	12/16	8/16	15/16	12/16	16/16	12/16
Optocouplers Black Overmold	Mechanical Failure- Gel Squeeze	13/16	14/16	14/16	15/16	16/16	15/16	16/16	16/16

Optocoupler B DOE 2



Optocoupler B DOE 2

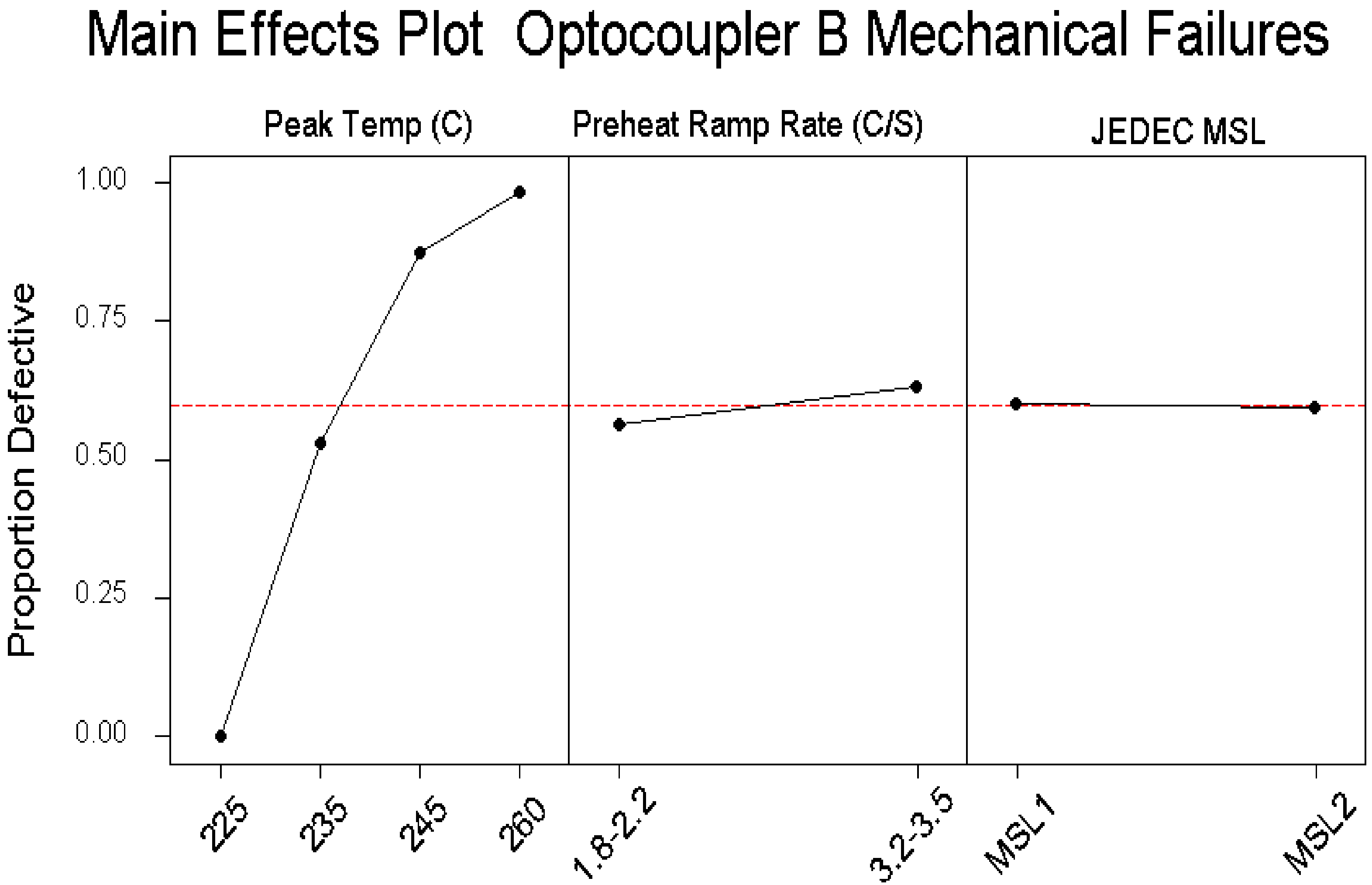


Optocoupler B DOE 2 Electrical Failures ANOVA

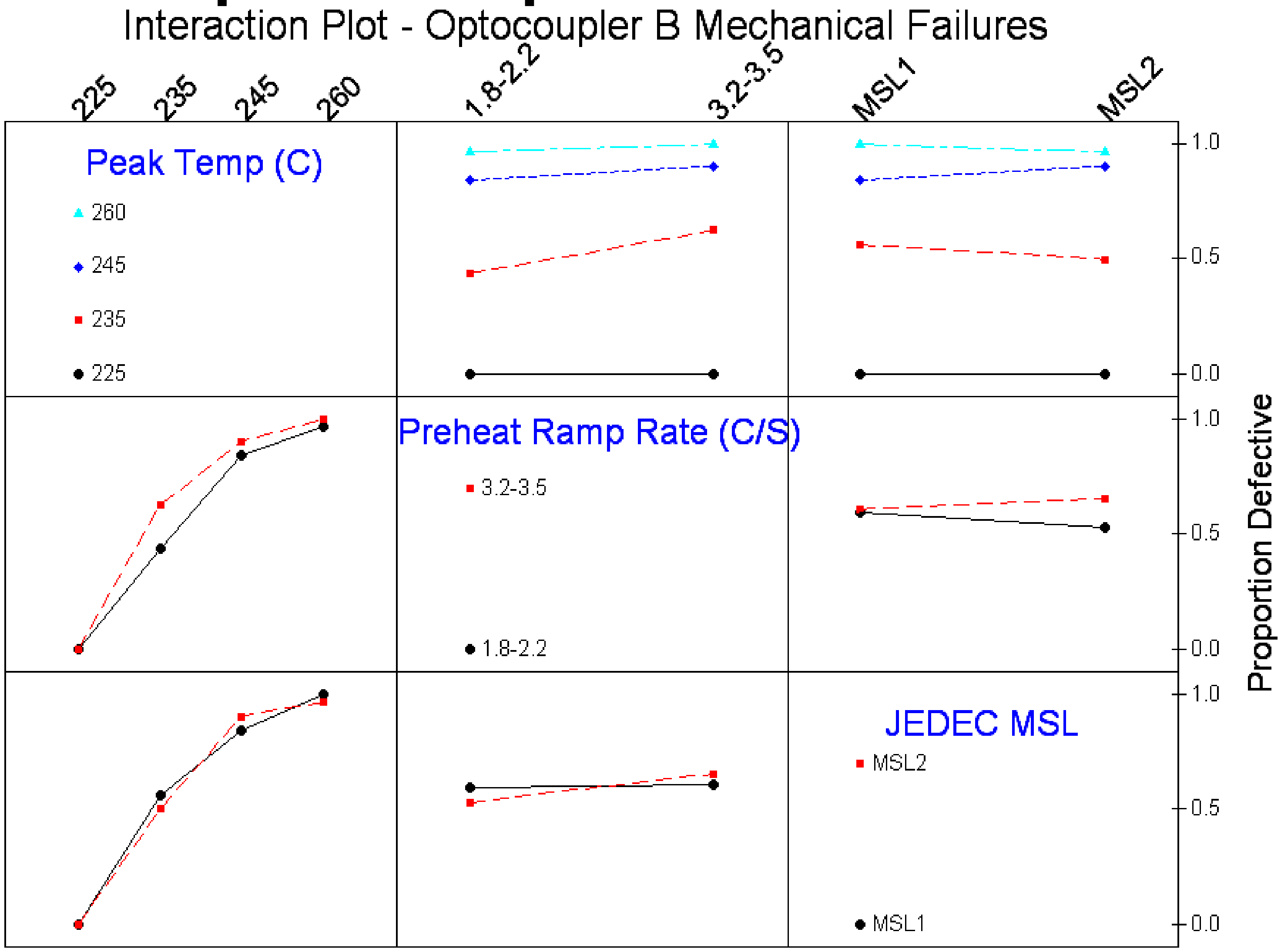
Source	Degrees of Freedom DF	Seq SS	Adj SS	Adj MS	F	P
Peak Temperature (Temp)	3	33.668	33.668	11.2227	102.36	**0.000**
Preheat Ramp Rate (Ramp)	1	0.0039	0.0039	0.0039	0.04	0.850
Levels	1	1.1289	1.1289	1.1289	10.30	**0.002**
Temp*Ramp	3	0.2305	0.2305	0.0768	0.70	0.552
Temp*Levels	3	0.4805	0.4805	0.1602	1.46	0.226
Ramp*Levels	1	0.0977	0.0977	0.0977	0.89	0.346
Temp*Ramp*Levels	3	0.0117	0.0117	0.0039	0.04	0.991
Error	240	26.3125	26.3125	0.1096		
Total	255	61.9336				

Peak Temp and Moisture Level main effects were both statistically significant factors at α=.1, The Peak Temp * Levels interaction effect was the next significant at a P-value of.226

Optocoupler B DOE 2



Optocoupler B DOE 2



Optocoupler B DOE 2 Mechanical Failures ANOVA

Source	Degrees Of Freedom	Seq SS	Adj SS	Adj MS	F	P
Peak Temperature (Temp)	3	37.6367	37.6367	12.5456	133.45	**0.000**
Preheat Ramp Rate (Ramp)	1	0.3164	0.3164	0.3164	3.37	**0.068**
Levels	1	0.0039	0.0039	0.0039	0.04	0.839
Temp*Ramp	3	0.3242	0.3242	0.1081	1.15	0.330
Temp*Levels	3	0.1367	0.1367	0.0456	0.48	0.693
Ramp*Levels	1	0.1914	0.1914	0.1914	2.04	0.155
Temp*Ramp*Levels	3	0.3867	0.3867	0.1289	1.37	0.252
Error	240	22.5625	22.5625	0.0940		
Total	255	61.5586				

Peak Temp and Preheat Ramp Rate main effects were both statistically significant factors at α=.1, The Ramp Rate* Levels interaction effect was the next significant at a P-value of.155

Conclusion

1) Some moisture sensitive components, defect rates increase as temperature increases along the range 225 C, 235C, 245 C, 260 C. See optocoupler B and PQFP.

2) For some moisture sensitive components, defect rates increase as preheat ramp rate increases from 1.8-2.2 C/S to 3.2-3.5 C/S, when preheat is defined as from room temperature to 120 C. See optocoupler B.

Conclusion

3) Some moisture sensitive components perform similarly at the same JEDEC MSL at lead free (SAC) and 63Sn/37Pb temperatures. See PLCC and TSOP S

4) When using moisture sensitive components for lead free applications, it is not sufficient to de-rate the JEDEC MSL one level such that a JEDEC MSL 2 63Sn/37Pb component becomes a JEDEC MSL 3 for lead free. Detailed JEDEC level qualification testing is needed before moisture sensitive components are subjected to lead fee soldering temperatures. See Optocoupler B.

Acknowledgements:

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All research was conducted at Endicott Interconnect Technologies, Inc.