IMPROVING THE DELAMINATION RESISTANCE BETWEEN DIE ATTACH MATERIAL AND LEAD FRAME PADDLE SURFACE THROUGH THE USE OF ROUGHENED LEAD FRAMES WITH BROWN OXIDE TREATMENT

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ABSTRACT

In the semiconductor packaging space, there are five (5) known forms of delaminations: die top delamination, die attach delamination, die paddle delamination (to surface and EMC), die paddle delamination (bottom paddle and EMC), and lead finger delamination. A delamination between the die attach material and the lead frame paddle has been detected after failure of the device at board-level testing; the delamination has manifested at the edge of the glue bondline within the fillet height. This paper aims to improve the delamination resistance between the die attach material and the lead frame surface using a lead frame with a roughened die paddle surface and has undergone Brown Oxide Treatment (BOT) to increase glue-paddle adhesion. It is known that BOT enhances the adhesion between the surface of the lead frame and the mold compound. However, in the case of this study, the adhesion enhancement on the surface is evaluated in terms of its resistance to delamination between the glue and the paddle surface. A comprehensive evaluation has been performed to emphasize the impact of using BOT lead frames, such that all other elements are held constant and only the lead frame material surface was left as variable. Furthermore, the evaluation has shown significant results in the improvement of delamination resistance between the glue and the paddle surface for QFN-mR packages, with corroborating data from forced delamination simulation and reliability evaluation.

1. 0 INTRODUCTION

Delamination is essentially described as a separation between the surfaces of two distinct layers that are supposed to be intact. The separation between the layers can be caused by a lot of factors such as, CTE (Coefficient of Thermal Expansion) mismatch between the materials, compatibility between the materials, materials property and composition, and the ability of the materials to withstand stresses under certain conditions, among others. It is also worth noting that in IC packaging and assembly, delamination comes in different forms (Fig. 1):

- Form 1: Die Top Delamination (Die Top and EMC)
- Form 2: Die Attach Delamination (Die Attach Material and Lead Frame Surface)
- Form 3: Die Paddle Delamination (Die Paddle Top Surface and EMC)
- Form 4: Die Paddle Delamination (Die Paddle Bottom Surface and EMC)
- Form 5: Lead Finger Delamination (Lead Finger Surface and EMC)

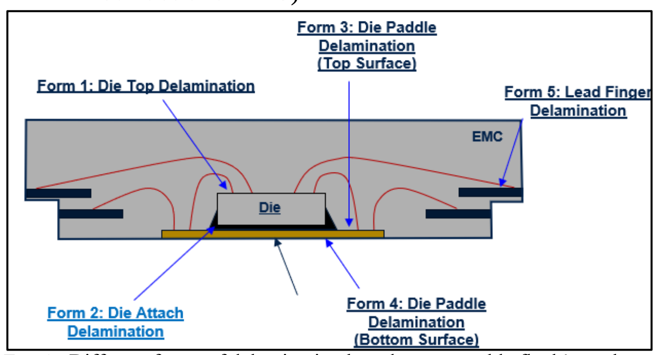


Fig. 1. Different forms of delamination based on a wettable flank's package design. The highlighted (colored in blue) form is the form involved in this paper; delamination between the die attach material and the lead frame paddle surface.

Lead frames play an important role in the assembly of an Integrated Circuit (IC), since it provides the base of the unit at the beginning of assembly. Majority of the key elements in an assembled IC is connected to the lead frame, such as the mold compound, the die attach material, and the wires themselves, as shown in Fig. 2. This relationship has paved the way for further development and improvement of lead frame finishes and surface integrities to improve the adhesion of these elements to the lead frame.

Most lead frame surfaces are finished with a relatively smooth surface (not perfectly smooth) with some selected areas that are etched for bondability, and areas or surfaces that are plated (pre-plated or post-plated) and/or coated with chemicals to improve performance. The most common plating material is Silver [Ag] and Palladium [Pd]; the choice of which depends on the design specifications, or with the intended performance. The final designs of the lead frames are dependent on the intended application of the chip.

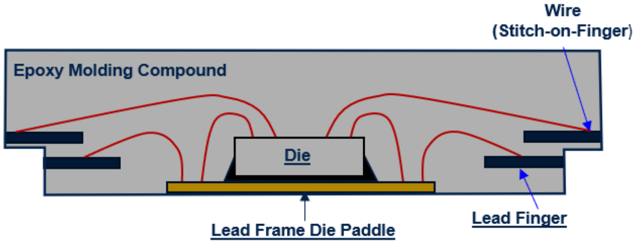


Fig. 2. Interactions of different assembly elements with respect to the lead frame surfaces and parts where they are adhered with.

Fig. 2 shows the interactions between the elements with the lead frame. The stitch of the wire interacts with the lead finger, or in some cases, on the die paddle. In addition, the die attach material interacts with the lead frame die paddle, and the epoxy molding compound interacts with the exposed elements of the lead frame, such as the die paddle, and the lead fingers.

2. 0 REVIEW OF RELATED WORK

2.1 Form 2: Die Attach Delamination

This delamination refers to a separation between the glue interface and the die paddle surface (Fig. 3). This is characterized by a "gap" between the surfaces of the two (2) layers, indicating a problem with the adhesion of the two surfaces. A lot of factors can be attributed with the presence of delamination, as it can present itself after time-zero curing or after extended reliability, specifically that of the thermal cycling process which increases the stresses experienced by the material.

There are a lot of factors that can be considered when it comes to analyzing die attach delamination, such as lead frame design, lead frame finishing, lead frame surface morphology, lead frame material composition, die attach material composition, and die attach process parameters, among others. In addition, the type of stresses induced on the package, as well as the environmental conditions are also factors to consider when analyzing delamination episodes. The most known cause of delamination is the CTE mismatch between the materials, such that the significant change in temperature induces significant amount of stress on the interface, causing the bond to weaken and delaminate.

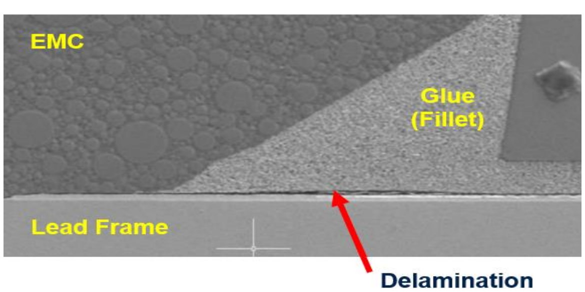


Fig. 3. Delamination manifestation between glue and the lead frame surface. The gap here has caused reading anomalies during testing at board level.

2.2 Brown Oxide Treatment

Brown Oxide Treatment (BOT) is a generic term that describes a chemical process that is applied to a surface of a metal substrate with the aim of forming an oxide layer that will serve as an adhesive promoter (Fig. 4), as reported by L.Chan, K. You Fai, and Y. Chun Ho. **[1]** The BOT technology has been originally developed for PCB laminates, that is, to enhance the adhesion between the copper circuitry and the laminated material, as reported by AAMI. Furthermore, it is also worth noting that recent developments in BOT have opened the door for modifications and adjustments with the chemical and mechanical processes involved in BOT to address the challenges brought about by BOT lead frames such as delamination and Non-Stick-on-Leads (NSOL), among others.

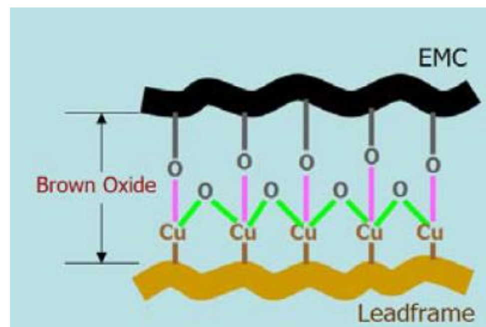


Fig. 4. Image adopted from L.Chan, K. You Fai, and Y. Chun Ho showing the representation of the interaction between the BOT lead frame with the EMC, as well as where is the specific Brown Oxide compounds are formed; they are formed on top of the lead frame surface.

The process of brown oxide treatment is a chemical process that involves a treatment that oxidizes the copper on the surface in an acidic medium to form the copper oxides. This chemical reaction, as reported by C. Wang, et al, involves copper oxides reacting with heterocyclic compounds that contain nitrogen, sulfur, and oxygen atoms under acidic conditions to form the brown oxide layer; the reaction is shown in the thermochemical equation (1) below. **[2]**

$$2Cu + H_2SO_4 + H_2O_2 + nA \rightarrow Cu_2SO_4 + 2H_2O + Cu[A]_n \quad (1)$$

Equation (1) shows copper oxide as the reaction product, generally represented as $Cu[A]_n$; the compound is formed after having Copper react with water [H_2O], sulfuric acid [H_2SO_4], hydrogen peroxide [H_2O2_2], and an additional reactant labelled as nA. The exact copper oxide compound formed from this reaction was not explicitly stated by C. Wang, et al. in their work. **[2]** Some possible copper oxide compounds for this reaction are Copper (I) Cu_2O oxide or Copper (II) CuO oxide; other forms of copper oxides are hypothetical and only exist in gas phase. It is also worth mentioning Cu_4O_3 a type of copper oxide which is also called as "Black Oxide".

2.3 Mechanical Interlocking of Roughened Surfaces

Adhesion refers to the state in which two dissimilar bodies are held together by intimate interfacial contact, such that mechanical force or work can be transferred across the interface, as reported by Wu S. In the case of this study, the dissimilar bodies are the surface of the die paddle and the glue. Collectively, there are five (5) types of adhesion: mechanical, electrostatic, chemical, dispersive, and diffusive. In the case, mechanical adhesion was considered.

Manoj M. has defined mechanical adhesion as the adhesion that takes place due to a mechanical interlocking between two dissimilar phases which attach to one another by mechanical forces only. This is commonly seen on polymeric materials, such as die attach materials (glue), wherein the glue flows into the tiny voids or spaces along the surface, causing and interlocking between them; the hardening of the glue causes a strong mechanical bond. **[3]**

Fig. 5 shows how the mechanical interlocking works on glue and die paddle surface. It shows as well how the roughening of BOT lead frames tends to create more voids for the glue to flow into and create stronger mechanical interlocking bonds since there will be a larger surface area where the glue contacts with the die paddle. In strength of materials, it is well-known that the more surface area means a stronger bond. **[3]**

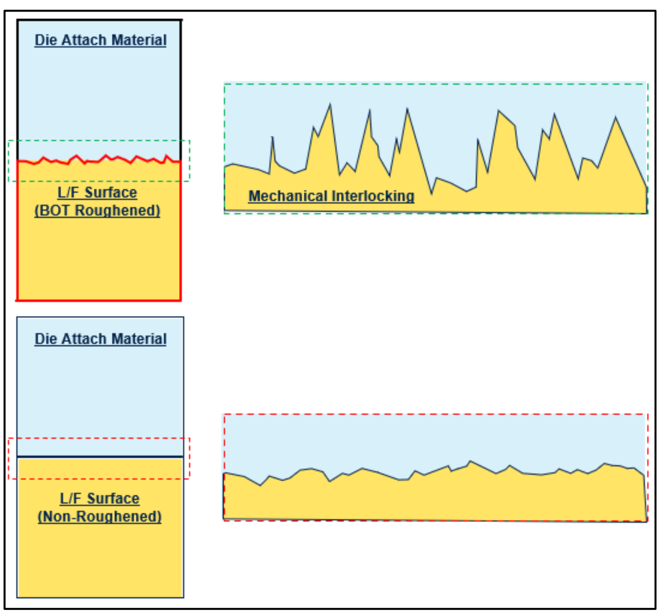


Fig. 5. Image representation inspired by Manoj M. Representation of how roughened surfaces produce mechanical interlocking between the glue and the lead frame surface as compared with the POR lead frame with lesser roughened surface.

Furthermore, Fig. 5 shows how the flow of the glue fills the gaps along the lead frame surface. Numerical values of the roughness of both lead frames are shown in Fig. 7.

3.0 METHODOLOGY

A feasibility build was assembled to evaluate the effectiveness of BOT lead frames in terms of die attach output responses and its resistance to delamination. Fig. 6 shows the actual lead frames used in the study. In addition, a forced delamination occurrence via Thermomechanical Analysis (TMA) was simulated to anticipate the reliability response of BOT lead frames, while the actual reliability samples were in progress.

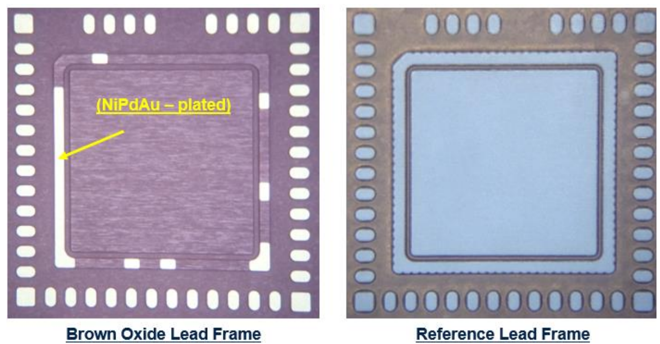


Fig. 6. Comparison between the lead frame with BOT and the reference lead frame. The NiPdAu-plated areas on the BOT lead frames were specifically designed since the test vehicle will have specific down bonds on those areas. It is known from previous evaluations that wires tend to have a difficult time bonding with bare brown oxide surfaces and often causes NSOL.

The build was assembled using dummy or mirror wafers since the primary objective is the improvement of the die paddle's surface resistance with form 2 delamination. All other materials were also held constant to be more consistent on the variation; die size, die material, die thickness, equipment, die attach material, and assembly processing parameters and conditions were all held constant as shown in Table 1. Furthermore, it is also worth noting that since the evaluation was done using mirror wafers, the wire bond output responses were waived; only wire bond heat simulation was done to complete the assembly conditions and be as close as possible with the reference.

Table 1. Feasibility Matrix

Element	POR	BOT L/F	REMARKS
Wafer Material	Mirror	Mirror	SAME
Die Thickness	280 um	280 um	SAME
Die Size	4.184 x 4.460 mm	4.184 x 4.460 mm	SAME
Die Attach Material	2A1 Glue	2A1 Glue	SAME
Lead Frame	Non-BOT (Non -Roughened)	BOT (Roughened)	VARIABLE
Assembly Equipment	Production Equipment	Production Equipment	SAME
Process Step Conditions	Production Parameters	Production Parameters	SAME

While the assembly of the feasibility was in progress, the surfaces of the die paddle from both lead frames were compared; the roughness value of both lead frames were considered. Fig.7 shows the morphology of both lead frames, as well as their roughness data.

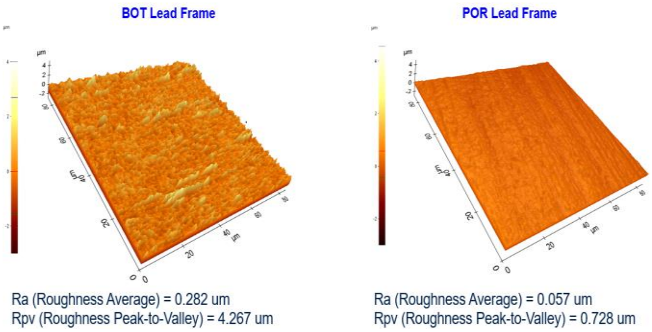


Fig. 7. Roughness comparison for both lead frames with both their photographical morphology representation, as well as with their numerical roughness data.

Die shear numerical values and die shear break mode were the primary data considered at assembly for the time-zero data comparison between the two frames; the data were statistically analyzed using JMP. Fillet height and bondline thickness (BLT) data were also considered. It is also worth to note that for the BOT lead frames, three (3) types of BOT lead frames were evaluated with the POR. These types of BOT lead frames have nothing to do with the surface finishing and surface roughening of the lead frame; they are different formulations for Anti-EBO (Epoxy Bleed-Out).

A forced delamination occurrence was simulated using TMA (Thermo-mechanical Analyzer) as shown in Fig. 8. This simulation was performed by putting the package inside the chamber, then ramping the temperature at 10 ‘C/minute from 25’C up to 320’C. The key indicator as to when to stop the TMA, is when the TMA curve has already shown a spike in the curve, showing the dimensional changes in the package; this abrupt change or spike in the graph confirms the manifestation of delamination.

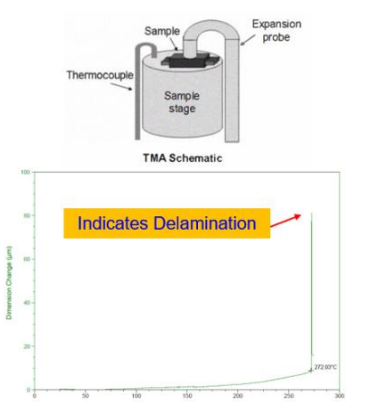


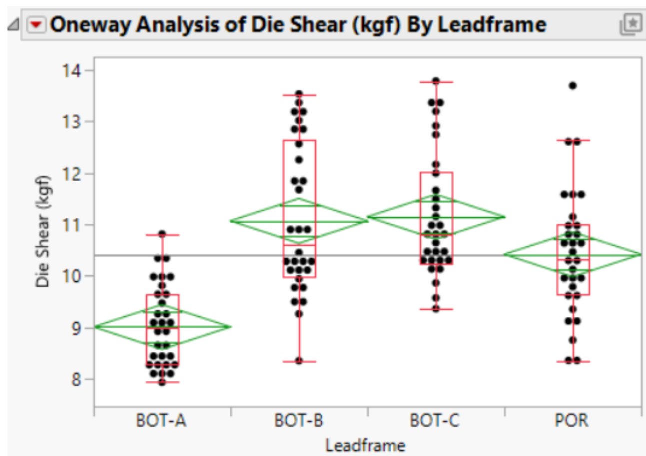
Fig. 8. TMA setup and graphical representation showing delamination.

Reliability evaluation was also done involving Moisture Sensitivity Level 1 (MSL 1) soak/reflow and thermal cycling. The condition for MSL 1 soak was following the Jedec standard (85°C/ 85% RH, 260°C 3x reflow). The thermal cycling condition used was set at -65°C/ 150°C.

4.0 RESULTS AND DISCUSSION

4.1 Time-Zero Die Attach Data

Hot Die Shear (HDS) test was performed for both the POR lead frame and the BOT lead frames. The same conditions were applied to be as consistent as possible. Looking at the JMP analysis shown in Fig. 9, BOT lead frames type B and C are having similar responses while the POR lead frame has a lower average, lower than types B and C BOT lead frames. It also shows that the roughened surface of the BOT lead frames gave a better adhesion between the glue and lead frame paddle surface based on die shear. Furthermore, in Fig. 10, it was evidently seen that based on the break modes comparison, the BOT lead frames have the better coverage.



Nonparametric Comparisons For All Pairs Using Dunn Method For Joint Ranking

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value
BOT-C	BOT-A	55.2667	8.981260	6.15355	<.0001*
BOT-B	BOT-A	50.0167	8.981260	5.56900	<.0001*
POR	BOT-A	37.2167	8.981260	4.14381	0.0002*
BOT-C	BOT-B	5.2167	8.981260	0.58084	1.0000
POR	BOT-B	-12.7667	8.981260	-1.42148	0.9311
POR	BOT-C	-18.0167	8.981260	-2.00603	0.2691

Connecting Letters Report

Level		
BOT-A	A	
BOT-B		B
BOT-C		B
POR		B

Levels not connected by same letter are significantly different.

Fig. 9. JMP analysis of the summarized numerical die shear data. The data of the BOT types B and C are higher than the POR, which shows improved adhesion based on the die shear test.

It is also worth noting that based on Fig. 9, BOT lead frame type A has the only significant results if we compare it with the POR. Although that is the case, it may be caused by the Anti-EBO formulation for this type of BOT, but that is not part of the scope of this paper. For BOT type B and type C, the difference that they have with the POR is not that significant, but what the evaluation wanted to show is that those two BOT lead frames have a relatively higher numerical data as compared with the POR and also passes the Cpk requirement.

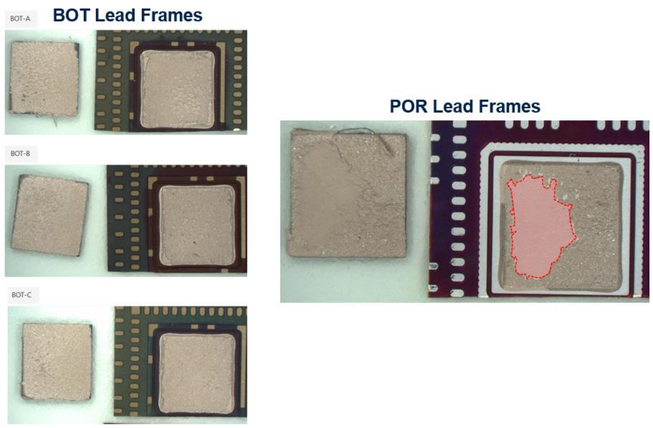
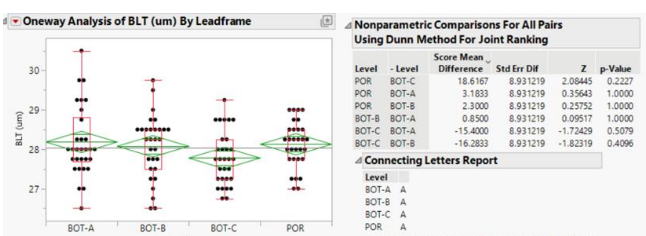


Fig. 10. Die shear break mode between the BOT lead frames and the POR lead frames.

The highlighted region on the POR lead frame shown in Fig. 10 shows that there is a big part (red) that has not left any glue artifacts, whereas with the BOT lead frames, almost the entire surface of the die paddle has glue artifacts. This implies a stronger adhesion between the die attach material and the surface of the die paddle; more surface area covered means stronger adhesion.

The BLT data show no significant difference between the BOT lead frames and the POR lead frame as shown in Fig. 11. All the BLT data are passing the Cpk requirement. Statistical analysis of the fillet height data (Fig. 12) indicates that only BOT-C has significant difference with POR. Though there is significant difference, it is still passing the required specification. The BLT and fillet height data show that for these specific characteristics, regardless of the lead frame being used, they are all passing the package's requirement.



Nonparametric Comparisons For All Pairs Using Dunn Method For Joint Ranking

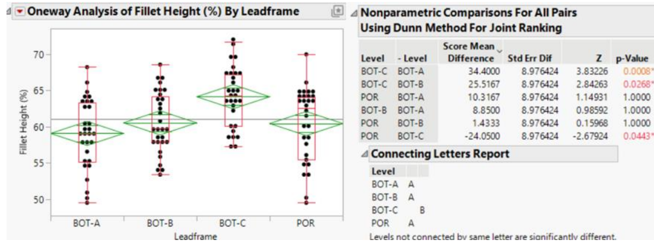
Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value
POR	BOT-C	18.6167	8.931219	2.08445	0.2227
POR	BOT-A	3.1833	8.931219	0.35643	1.0000
POR	BOT-B	2.3000	8.931219	0.25752	1.0000
BOT-B	BOT-A	0.8500	8.931219	0.09517	1.0000
BOT-C	BOT-A	-15.4000	8.931219	-1.72429	0.5079
BOT-C	BOT-B	-16.2833	8.931219	-1.82319	0.4096

Connecting Letters Report

Level	
BOT-A	A
BOT-B	A
BOT-C	A
POR	A

Levels not connected by same letter are significantly different.

Fig. 11. JMP analysis for the BLT data between BOT and POR lead frames. No significant difference.



Nonparametric Comparisons For All Pairs Using Dunn Method For Joint Ranking

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value
BOT-C	BOT-A	34.4000	8.976424	3.83226	0.0008*
BOT-C	BOT-B	25.5167	8.976424	2.84263	0.0268*
POR	BOT-A	10.3167	8.976424	1.14931	1.0000
BOT-B	BOT-A	8.8500	8.976424	0.98592	1.0000
POR	BOT-B	1.4333	8.976424	0.15968	1.0000
POR	BOT-C	-24.0500	8.976424	-2.67924	0.0443*

Connecting Letters Report

Level		
BOT-A	A	
BOT-B	A	
BOT-C		B
POR	A	

Levels not connected by same letter are significantly different.

Fig. 12. JMP analysis for the fillet height data (% of die thickness) between BOT and POR lead frames.

4.2 Forced Delamination Simulation (TMA)

Using TMA, form 2 delamination was forced to occur to the samples. The aim was to predict the enhanced adhesion between the die attach material and the roughened lead frame surface with BOT. The simulation results shown in Fig. 13 indicate how the delamination behaved with different lead frames (BOT vs POR) during the simulation.

The delamination on the BOT lead frame is COHESIVE – the separation was within the glue, and there was no separation seen between the surface die paddle and the glue. On the other hand, the POR lead frame is INTERFACIAL – the separation was between the interface of the glue and the surface of the die paddle. The roughening of the surface, as discussed in Fig. 5 shows that the resulting mechanical interlocking between the glue and the surface has caused a strong adhesion; the HDS modes of the BOT and POR lead frames corroborate the strength of mechanical interlocking.

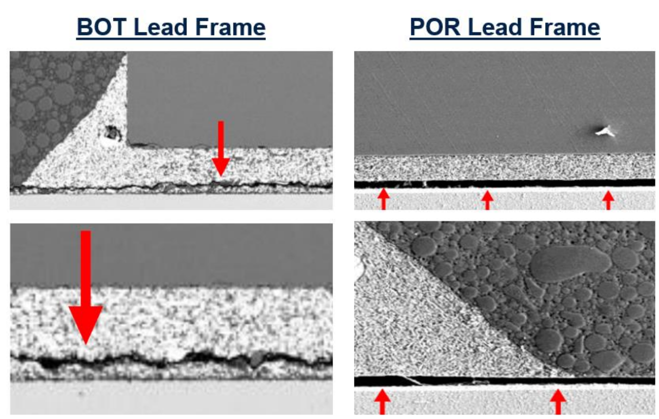


Fig. 13. Forced delamination comparison between BOT lead frame and POR lead frame.

4.3 Reliability Evaluation

The reliability evaluation (MSL 1, thermal cycling) has shown significant improvement with delamination performance of BOT lead frames as shown in Table 2. The POR has delamination at the outer die pad after MSL 1 or moisture soak and reflow. However, all the BOT units (BOT-A, BOT-B, BOT-C) have no delamination up to TC 500.

These results further confirmed the superior performance of BOT lead frames against delamination.

Table 2. Reliability Test Results

ST Lot ID	LEG1 POR	LEG2 BOT - A 280 um/2A1	LEG3 BOT - B 280 um/2A1	LEG4 BOT - C 280 um/2A1
T0 SAM	Done	Done	Done	Done
MSL1	Done	Done	Done	Done
SAM	With outer pad delam	No delam	No delam	No delam
TC100	Done	Done	Done	Done
SAM	With outer pad delam	No delam	No delam	No delam
TC200	Done	Done	Done	Done
SAM	With outer pad delam	No delam	No delam	No delam
TC500	Done	Done	Done	Done
SAM	With outer pad delam	No delam	No delam	No delam

5.0 CONCLUSION

The main objective of this study was to increase the resistance of the device from form 2 delamination using a roughened lead frame surface with Brown Oxide Treatment. The numerical data of hot die shear proved to have improved the adhesion between the glue and the surface of the lead frame. We can see that there are significant differences in their numerical values, not to mention the break mode results that have explicitly showed which of the two lead frame types had the better adhesion. In addition, the BLT numerical values were significant as well. Moreover, the numerical data the fillet height showed no significant difference between the BOT and the POR lead frame, which shows that regardless of the lead frame type, they will still adhere with the device's requirements. Finally, the forced delamination experiment has shown that the BOT lead frame had a better adhesion; the mechanical interlocking adhesion mechanism has played a big role with these positive results. The delamination that was seen from the BOT lead frame is COHESIVE, as compared with the POR lead frame which showed an INTERFACIAL delamination. The roughening and BOT on the lead frame has enhanced the resistance of the device from form 2 delamination (interfacial). Reliability results have also confirmed the elimination of delamination with the use of BOT lead frame.

6.0 RECOMMENDATIONS

Based on the positive results of the evaluation, it is recommended to use roughened lead frames with BOT for other devices. Extending the reliability tests or subjecting the package to worst stress conditions such as during SMT processes are also recommended to ensure the robustness of the BOT lead frame solution. Other BOT technologies and methodologies from different suppliers can also be explored.

7.0 ACKNOWLEDGMENT

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