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Package Voids Reduction through Effective use of Defect Mapping Analysis in a reel-to-reel Film-assisted Transfer Molding Process

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Abstract— *Secure micromodule metal leadframe-based card embedders are widely used for passport and credit card applications. It utilizes film-assisted transfer molding technique as its encapsulation technology. Since the start of early production stage, chronic package void rejects are encountered which accounts as top defect contributor at molding station. This high package voids rejection rate at mold process significantly impacts the assembly yield performance. Hence, it is necessary to reduce or eliminate package voids rejection in order to improve the overall yield.*

This technical paper discusses the various DMAIC tools and methodology, including the use of comprehensive defect mapping analysis which was remarkably beneficial in eventually identifying a mold tool design limitation. Inevitably, mold tool design modification was performed to significantly reduce the package voids defect thus helped improve the overall yield for secure micromodule product.

Keywords— *DMAIC; Film-asisted Transfer molding; Package Voids Reduction; Reel-to-reel process.*

I. Introduction

Secure micromodule card embedder is a 2-contact module made on super 35-mm metal leadframe (reel form). This product utilizes dark green molding compound as its protective coating which highly requires it to be processed on a reel-to-reel film-assisted transfer molding equipment. This card embedder is specifically developed for assembly in smartcards and inlays to provide support for the chip, electrical contacts, and suitable assembly interface for modules used in passport and credit card products. The device comprises of a 50 micron-thick smartcard crystal interconnected to a 60 micron-thick silver-plated copper foil leadframe via film die-attach and 0.8 mil gold wirebonding technology. Mold cap dimension is 5.0 mm x 5.0 mm x 0.190 mm with corresponding package outline of 5.6 mm x 8.0 mm x 0.250 mm.

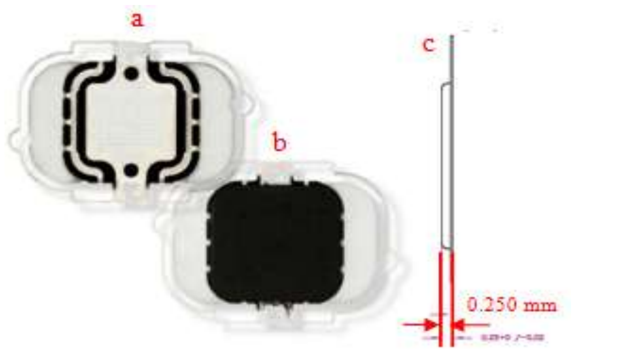

Figure 1. Secure micromodule card embedder (a-contact side, b-mold side, c-cross-section view)

The inherent thin mold cap dimension poses a challenge in properly encapsulating the device free from any cosmetic defect on mold surface and periphery.

1.1 Define Phase

1.1.1 Overall yield performance

Overall yield in secure micromodule product is not consistently met during early production phase. The average yield is 0.27% below the set target.

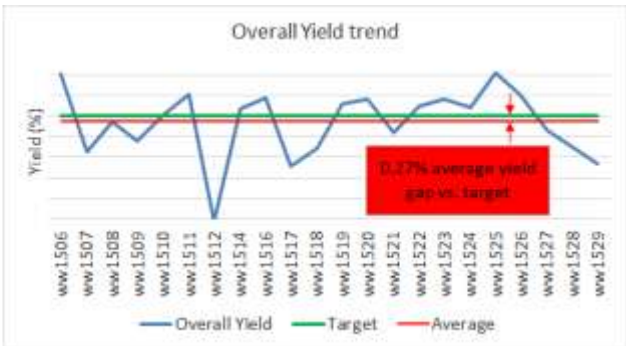

Figure 2. Overall yield trend during early production phase

1.1.2 Mold defect pareto

Package voids is the top mold defect contributor based on the early production mold defect pareto. The average package voids PPM-defect rate encountered during this time period contributes to 42% of the total mold station defects.

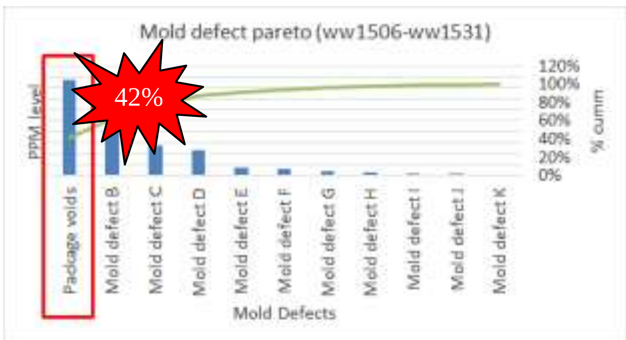

Figure 3. Mold defect pareto

1.1.3 Film-assisted transfer mold process description

The following sub-sections explain the essential materials and tool used for molding secure micromodule product.

1.1.3.1 Dark green mold compound

Dark green epoxy resin are observed to be the stickiest type of molding compound. This is mainly due to its inherently minimal CTE or coefficient of thermal expansion. Upon mold tool opening, molded package need to easily separate from the mold tool cavity. However, dark green mold compound will not help respond accordingly since it has very minimal change in size. Contrariwise, packages using non-green mold compounds are easier to release from the mold tool due to higher CTE.

1.1.3.2 Mold release film

To keep efficient molding operation, top and bottom mold release films are employed. These mold release films primarily help improve separation of the molded package from the top and bottom mold tool after each mold shot preventing mold sticking and potential package crack. Likewise, mold flashing is minimized with the aid of the top and bottom mold release films. The mold release films are vacuumed to the mold tool prior transfer molding.

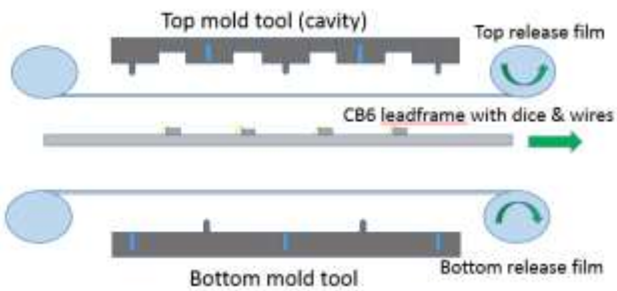

Figure 4. Reel-to-reel film-assisted transfer molding configuration

1.1.3.3 Mold tool configuration

Three mold cavity blocks comprise the top mold tool namely left, center and right mold tool cavity blocks. Each mold cavity block is composed of 3 rows x 12 columns cavity matrix, 36 modules in total. A single pellet is assigned to deliver mold compound to each cavity block via mold runners. Together, the three mold cavity blocks enable encapsulation of 108 modules per mold shot. Mold cull bridges are situated in between the mold cavity blocks to help compensate difference in weight of the pellets, and/or mechanical differences in tool and/or plunger.

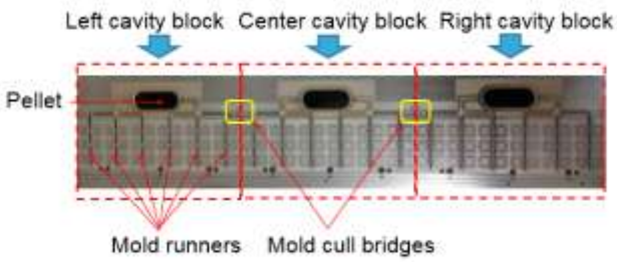

Figure 5. Top mold tool configuration

Each module cavity has individual mold gates where mold compound enters the mold cavity and a pair of air vents to release entrapped air during transfer molding.

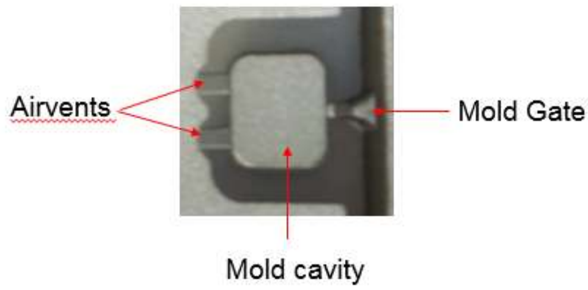

Figure 6. Individual module cavity

1.2 Map and Measure Phase

1.2.1 Macro map

Package voids defect generally originate from the mold process thus focus of the project is at this particular station.

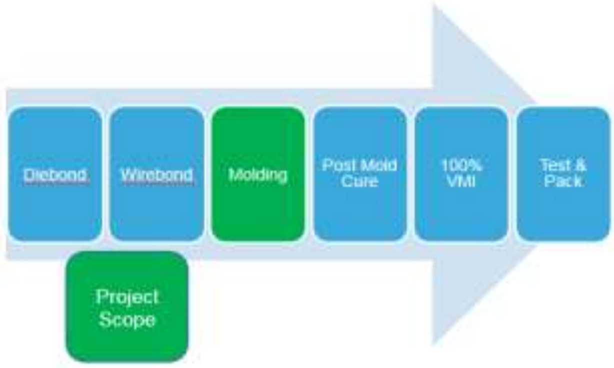

Figure 7. Macro process flow

1.2.2 Package voids defect signature

Figure 8 below shows the package voids defect signature. Adjacent modules typically encounter package voids as shown encircled in red. Due to the inherently low package thickness, voids are very easy to notice during inspection appearing as a whitish spot on the mold surface. As per visual inspection criteria, any module exhibiting void or pin hole greater than 100 microns in diameter is unacceptable. These voids or pinholes are normally entrapped air during mold transfer which presents reliability risk to the product.

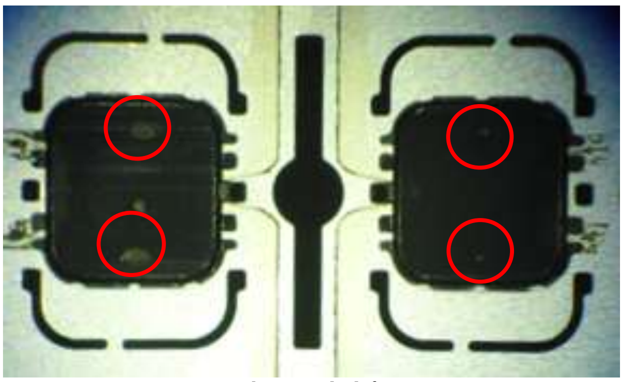

Figure 8. Package voids defect signature

1.2.3 Defect mapping

A comprehensive defect mapping analysis was performed in order to help draw out clues on the potential root cause/s of package voids or pinholes. Location of the package voids defect per mold shot was recorded and summarized to show the location concentration of package voids defects per mold shot. Each module location was designated with a unique row and column identification. Module rows were designated as rows A to C starting from the top to the bottom row accordingly. While module columns were designated columns 1 to 36 starting from the left to the right column accordingly. To illustrate further, upper-left most module is designated as module 1A while lower-right most module is designated as module 36C. Refer to figure 9 below.

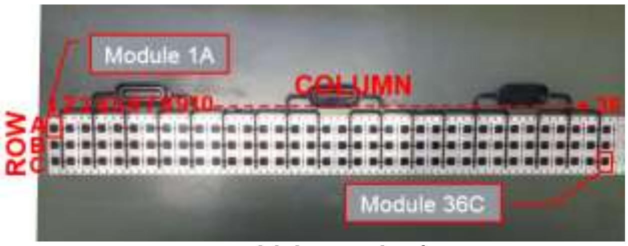

Figure 9. Module location identification

Based on the result of the defect mapping analysis, the package voids defect are localized on modules 13A, 14A, 23A, 24A, 23B, and 24B which seemingly appear in pairs. These six particular module locations contribute to 95.8% of the total package voids defect captured during inspection. Moreover, all these identified modules are situated in the center mold cavity block. Succeeding investigations and evaluation will utilize these important observation and information gathered.

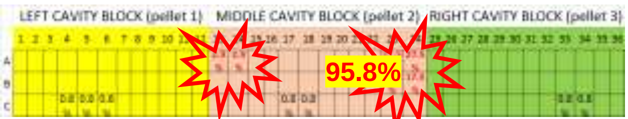

Figure 10. Defect mapping result

1.2.4 *Visual and mechanical inspection capability*

Visual and Mechanical Inspection or VMI operators undergo extensive qualification and certification process before being allowed to perform 100% inspection of molded packages. Various trainings and exercises coupled with written and hands-on assessments are thoroughly conducted. Operator inspection performances are also monitored regularly even after qualification and certification. This is very important to always ensure that precise disposition are carried out on inspected units versus set criteria to help avoid over or under rejection. Proper defect charging is also followed to ensure accurate analysis and well established solutions.

1.2.5 *Current process performance*

High package voids defect PPM rate is encountered during the early production phase of secure micromodule product. Average defect PPM rate is exceeding the set target by 768%. This denotes that the present package voids rejection rate is almost 8 times higher than the established defect PPM target limit.

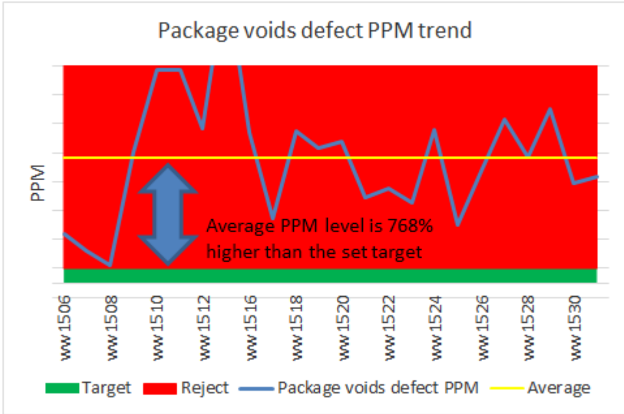

Figure 11. Current package voids trend

II. Experimental Section

2.1 *Analyze Phase*

2.1.1 *Cause and effect diagram*

Based on the observed location concentration of the package voids defect, several potential causes were enumerated. Through the use of fishbone diagram, all the potential causes related to the localized package voids were identified in increasing detail.

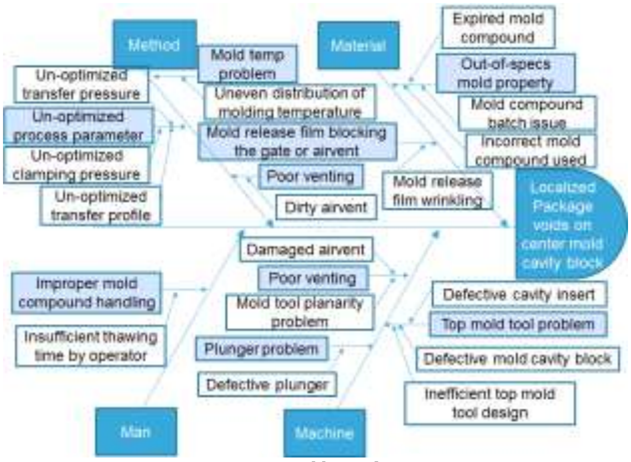

Figure 12. Fishbone diagram

Table 1. Summary of potential causes

Problem: Localized package voids on center mold cavity block.	
Cause ID	Potential cause description
Cause 1.1	Insufficient thawing time by operator
Cause 2.1.1	Damaged air vent
Cause 2.1.2	Mold tool planarity problem
Cause 2.2	Defective plunger
Cause 2.3.1	Defective cavity insert
Cause 2.3.2	Defective mold cavity block
Cause 2.3.3	Inefficient top mold tool design
Cause 3.1.1	Un-optimized transfer pressure
Cause 3.1.2	Un-optimized clamping pressure
Cause 3.1.3	Un-optimized transfer profile
Cause 3.2	Uneven distribution of molding temperature
Cause 3.3	Dirty air vent
Cause 4.1.1	Expired mold compound
Cause 4.1.2	Mold compound batch issue
Cause 4.1.3	Incorrect mold compound used
Cause 4.2	Mold release film wrinkling

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The potential causes were grouped in to four major categories namely Man, Machine, Method, and Material. In summary, there were 16 potential causes identified. Each potential cause was assigned an identification as shown on table 1.

2.1.2 Identification of controllable root cause

The 16 potential causes identified from the fishbone diagram were individually analyzed and validated to help identify the true cause. As a result, there were 15 invalid causes and only 1 true and valid cause.

Table 2. Summary of root cause identification

Potential Cause	Method of Validation	Result of Validation	Conclusion	Controllability
Cause 1.1	Processed known good mold compound (Run 1)	Same package voids defect location	Invalid	
Cause 2.1.1	Swapped center mold cavity block with left cavity block (Run 2)	Same package voids defect location	Invalid	
Cause 2.1.2	Performed mold tool planarity checking	Balanced clamping observed as per paper imprint result	Invalid	
Cause 2.2	Swapped center plunger with left plunger (Run 3)	Same package voids defect location	Invalid	
Cause 2.3.1	Swapped center mold cavity block with left cavity block (Run 2)	Same package voids defect location	Invalid	
Cause 2.3.2	Swapped center mold cavity block with left cavity block (Run 2)	Same package voids defect location	Invalid	
Cause 2.3.3	Temporarily blocked the cull bridges using blue silicone (Run 5)	Package voids was significantly reduced	Valid	Within control
Cause 3.1.1	Processed using optimized mold parameter (Run 4)	Same package voids defect location	Invalid	
Cause 3.1.2	Processed using optimized mold parameter (Run 4)	Same package voids defect location	Invalid	
Cause 3.1.3	Processed using optimized mold parameter (Run 4)	Same package voids defect location	Invalid	
Cause 3.2	Performed mold temperature check	Balanced mold temperature	Invalid	
Cause 3.3	Performed mold tool cleaning	Same package voids defect location	Invalid	
Cause 4.1.1	Processed known good mold compound (Run 1)	Same package voids defect location	Invalid	
Cause 4.1.2	Check Certificate of Conformance	Mold compound within specs	Invalid	
Cause 4.1.3	Processed known good mold compound (Run 1)	Same package voids defect location	Invalid	
Cause 4.2	Performed mold release film check upon vacuum to top tool	No mold release film wrinkling observed	Invalid	

2.1.2.1 Run1: Known good mold compound processing

One lot was processed and monitored to check and validate if the localized package voids observed are caused by mold compound handling or material issue. Based on the result, known good mold compound still yields package voids on the same mold cavity locations. In summary, performing this simple experiment invalidates altogether cause 1.1, cause 4.1.1, and cause 4.1.3.

2.1.2.2 Run 2: Mold cavity block swapping

Since package voids defect are localized in the center mold cavity block, a simple experiment was devised to validate if it is caused by a specific mold cavity problem. The center mold cavity block was interchanged with the left mold cavity block. Subsequently another lot was processed and monitored for package voids occurrence. The same defect location was observed upon inspection thus invalidating altogether cause 2.1.1, cause 2.3.1, and cause 2.3.2.

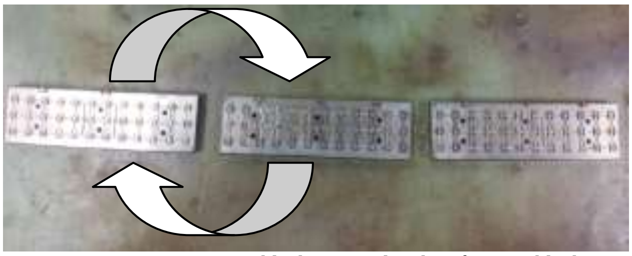

Figure 13. Center cavity block swapped with Left cavity block

2.1.2.3 Run 3: Plunger swapping

Mold plunger was also checked for potential contribution to the localized package voids problem. Since each cavity block utilizes specific plungers, it was worthwhile to verify the effect of interchanging plungers. Center mold plunger was exchanged with the left mold plunger and afterwards processed another lot and then checked for package voids rejection. Unfortunately, package voids was still localized on the same area therefore invalidating cause 2.2.

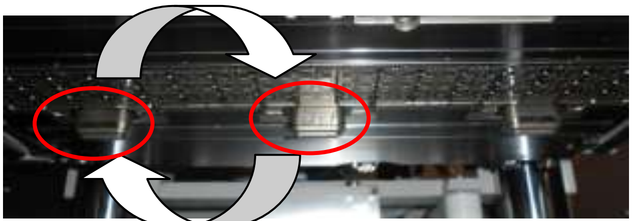

Figure 14. Center plunger swapped with Left plunger

2.1.2.4 Run 4: Mold parameter optimization

Factors related to mold parameter were analyzed to verify contribution to localized package voids defect. A short shot was performed initially to observe the mold flow behavior. Several experimental runs simulating different optimized mold parameters were performed in order to check if package voids defect signature will at least change in appearance, behavior or location. Eventually, no amount of mold parameter alteration and combination was successful enough to influence any change in the defect's observed behavior. Based on these series of evaluations, cause 3.1.1, cause 3.1.2, and cause 3.1.3 were all invalidated.

Table 3. Mold parameter optimization summary

	Clamp pressure	Transfer pressure	Transfer speed	Result
1	Low	Low	Slow	Same package voids level and defect location
2	High	Low	Slow	
3	Low	High	Slow	
4	High	High	Slow	
5	Low	Low	Fast	
6	High	Low	Fast	
7	Low	High	Fast	
8	High	High	Fast	

2.1.2.5 Run 5: Mold cull bridge blocking

With all other potential causes invalidated, mold tool design was finally examined. The defect mapping result was a key information in building a hypothesis that a potential flaw in the mold design is possibly contributing to the observed package voids localization.

2.1.2.5.1 Defect mechanism hypothesis

The modules normally affected with package voids are the ones near the area where mold compound from the adjacent pellets are initially meeting during transfer molding. This paved way to the idea that entrapped air is probably produced at the cull bridge area where the adjacent pellets meet up and the air pocket generated is transferred primarily to the nearest mold cavities resulting to the package voids localization observed.

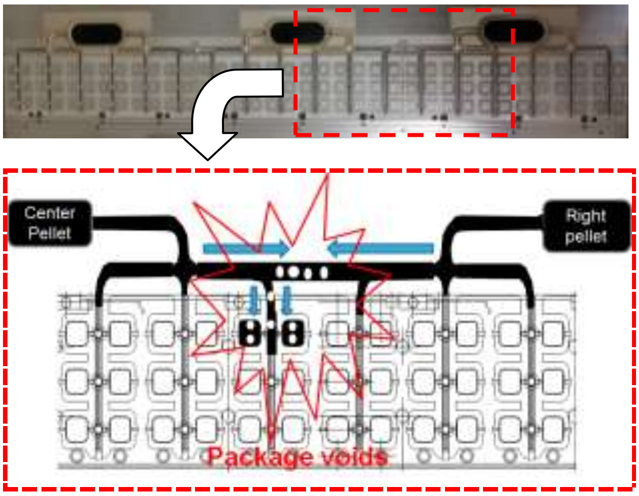

Figure 15. Package voids defect mechanism

2.1.2.5.2 Method of validation

To validate if air pockets are indeed produced by the colliding mold flow from the adjacent pellets, it was determined to temporarily block the cull bridges using blue silicone material. This way, mold flow from adjacent pellets will be prevented from meeting up thus preventing entrapped air generation.

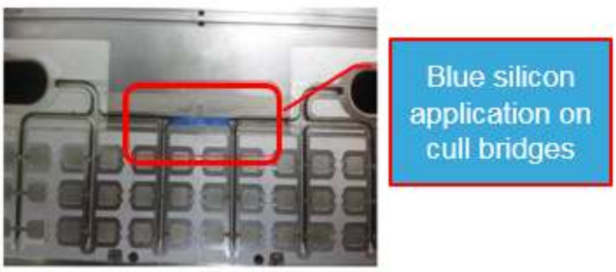

Figure 16. Temporary blocking of cull bridges

2.1.2.5.3 Result of validation

Significant reduction of package voids reject was instantly observed after temporary blocking the cull bridges. Additionally, previous defect localization was not evident any longer. A total of 16 production lots using blocked cull bridge were processed to help compare the performance versus the production lots using typical non-blocked cull bridge condition. A significant package voids defect PPM reduction of 3600% was achieved. Moreover, the defect PPM for the production lots using the blocked cull bridge is substantially meeting the set PPM target.

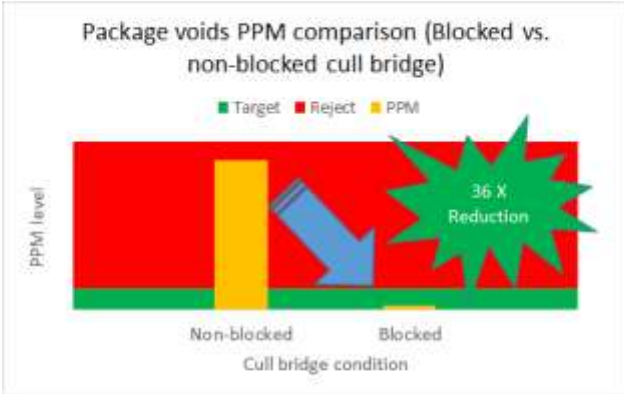

Figure 17. Blocked vs non-blocked cull bridge validation summary

To statistically prove that blocked cull bridge will result to better package voids performance, 2-proportion test was utilized. Based on the 2-proportion test result, the blocked cull bridge has significantly lesser package voids than non-blocked cull bridge at better than 95% confidence level. P-value (Left) is greater than 0.05 indicating that the blocked cull bridge is significantly better than non-blocked cull bridge in terms of package voids defect rate.

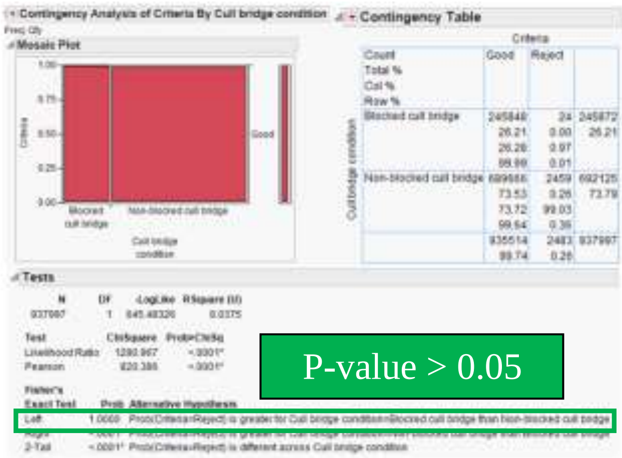

Figure 18. Two-proportion test summary

III. Results and Discussion

3.1 Implementation phase

3.1.1 Best solution identification

With the positive result achieved by temporary blocking the cull bridges, mold tool modification was necessary. Permanent blocking of cull bridges using tool inserts was the best solution to undertake. This action is categorized as error proofing or EP level 1 since it ensures to eliminate the risk of building air pocket due to adjacent pellets' mold flow collision during mold transfer.

Figure 19. Cull Bridge blocking insert design

3.1.2 *Verification of solution effectiveness*

To ensure that planned solution is indeed effective, blue silicone was removed and re-applied to the existing mold cull bridge. This is to turn-on and turn-off the localized package voids defect. This will guarantee the solution effectiveness and decide whether to pursue the planned tool modification or not. Based on the result, significant effect on package voids performance was observed upon removing and re-applying the blue silicone. Thus, decision was to pursue the mold tool modification action.

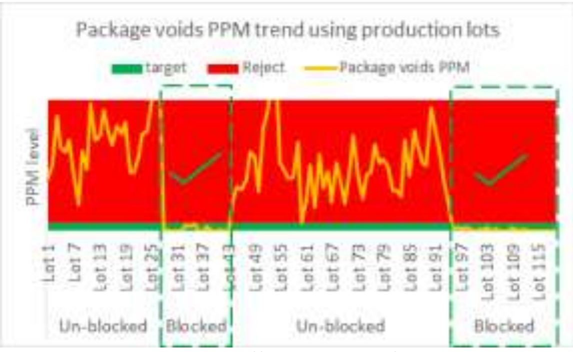

Figure 20. Solution effectiveness verification result

3.1.3 *Potential problem analysis*

The risks involved in implementing the final solution should be assessed likewise. Potential problem analysis ensures that the best solution will not incur new issues upon completion.

Table 4. Potential problem analysis summary

Best Solution	Potential Problem	Potential Causes	Counter preventive Actions	EP Level	Status	Resp.
Mold tool modification	Mold bleeding	Excess mold compound during mold transfer	Optimize cull height setting	2	Done	S. Salivio
	De-culling problem	Cull bridge blocking will alter mold cull design and appearance	Check position of de-culling sensors. Monitor de-culling errors related to blocked cull bridge.	8	Done	S. Salivio
	Unbalanced mold tool planarity	Incorrect cull bridge blocking insert installed	Communicate with OEM. Send actual mold tool for precise insert design and fitting.	8	Done	LJ. Manuel
	Production downtime	No mold tool to use during tool modification	Schedule tool modification during plant shutdown	5	Done	LJ. Manuel

Note: OEM – Original Equipment Manufacturer

It is a proactive approach to establish controls or countermeasures that are necessary before putting the best solution in place.

3.1.4 *Implementation plan*

Timeline to complete the mold tool modification was also prepared to achieve a smooth production implementation of permanent corrective action. Temporary cull bridge blocking was maintained prior mold tool modification.

Table 5. Implementation plan time table

Best Solution	Steps (How)	Implementation Date							Resp.	Remarks
		Plan vs. Actual	WW 1547	WW 1548	WW 1551	WW 1552	WW 1601	WW 1602		
Mold tool modification	Design inserts	Plan							OEM	Design review and approval
		Actual								
	Manufacture inserts	Plan							OEM	
		Actual								
	Send mold tool set to OEM	Plan							ST	Production shutdown
		Actual								
	Modify top mold tool and fit inserts	Plan							OEM	
		Actual								
	Send modified mold tool set to ST	Plan							OEM	
		Actual								
	Mold tool installation and buy-off	Plan							ST	
		Actual								
	Production run	Plan							ST	6 lots processed
		Actual								

3.1.5 *Description of best solution*

Below shows a snapshot of the benefits gained from the identified best solution. It also illustrates the difference between the old and the new cull bridge design.

Table 6. Description of best solution

Problem	Localized package voids due to air pocket build-up at mold cull bridge area	
Action	Mold tool modification. Install blocking insert at mold cull bridge area.	EP Level 1
BEFORE	AFTER	
		
Without blocking insert	With blocking insert	
Results: High occurrence of localized package voids	Results: Significant reduction of package voids	

3.2 *Control Phase*

3.2.1 *Evaluation of results*

Starting WW1547, package voids PPM and overall yield targets were consistently met. The temporary blocking of mold cull bridges instantly resulted to a significant decrease in package voids by an average of 9000% compared to previous production performance. This is equivalent to 90 times reduction in PPM level, thus substantially meeting the package voids defect PPM target. This was further confirmed by the initial production result after mold tool modification last

WW1602. Accordingly, overall yield increased by an average of 0.47% thus meeting the set overall yield target.

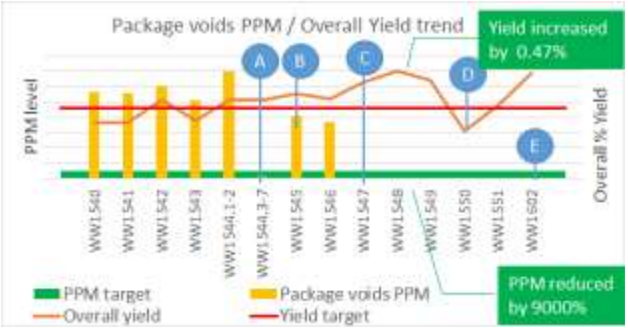

Figure 21. Implementation Result

Notes: A – Applied blue silicone (temporary blocking of cull bridges)
B – Removed blue silicone
C – Re-applied blue silicone
D – High scrapping at VMI due to assignable front-of-line defect
E – Utilized modified mold tool for production

3.2.2 Documentation

Failure mode and Effects Analysis document for film-assisted transfer molding was revised and updated to reflect the changes and improvements made through this project.

IV. Conclusion

Mold tool modification significantly helped reduce package voids failure for micromodule metal leadframe-based card embedders. The mold cull bridge blocking solution eliminated the risk of generating air pockets during mold transfer thus preventing package voids. Simple use of defect mapping analysis tool and keen observation of gathered data to serve as clue remarkably helped identify the root cause of the problem leading to the identification of best solution. This improvement also translated to overall yield increase therefore help save on cost due to unnecessary scrapping of products.

V. Recommendations

It is recommended to fan-out the mold tool modifications completed to future reel-to-reel transfer molding machine acquisitions. The improvements implemented will be part of the buy-off and purchasing specs criteria for similar mold tooling and technology.

Acknowledgment

The author wish to thank the mold machine manufacturer for the openness and support in the resolution of the problem. Assistance from line sustaining and production team was also valuable in completing this project.

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