Capacity Improvement for Transfer Molding Trough Reduction of Mold Curing Time

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Authors' contributions

This work was carried out in collaboration between both authors. Author MGRM designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors LJTB managed the analyses of the study, managed the literature searches. Both authors read and approved the final manuscript.

Article Information

Original Research Article

ABSTRACT

This paper will discuss the improvement made to increase machine capacity in order to be prepare for incoming demand ramp-up and to free up machine allocation to back-up automotive machine. Using DMAIC methodology (Define, Measure, Analyze, Improve and Control) approach, mold curing time identified as the top contributor during time study of the process with 120 secs consumed time per shot. A Differential Scanning Calorimetry (DSC) and Curability Curve study for molding compound was conducted from both internal and external expertise to get the optimum lower range of cure time. Considering all the quality risk using Risk assessment, the success of reducing Mold curing time from 120secs to 80secs increases 25% machine capacity of transfer Molding for Quad Flat No leads(QFN) / Quad Flat No leads multi-Row(QFN-mR) with significant cost savings. The project was able also to free up 3 molding system to support upcoming products.

Keywords: Capacity; transfer mold; mold curing time; cure time reduction.

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1. INTRODUCTION

Capacity determines the manufacturing capability in producing output product to comply the trend of supply and demand. Now a days, a fast-moving trend of producing products for technologies is very critical for a semiconductor industry [1,2]. A Company must adopt immediately and produce faster while demand moving increasingly. Faster production means high capacity which the supplier needs to comply with the demand. In a Semiconductor, capacity is the quantity of the Integrated Circuit (IC) units produced on a given time based on the available resources (Machine design, number of mold press and material design). Time is one of the factors that dictates manufacturing capacity of the process [3-5]. The period to maximize the IC production determines company productivity. The faster processing, the larger capacity to produce an IC. Increasing the ability to produce product is not easy, quality of the product must be considered and must be attain based on customer desire. Producing high quantity and high quality is the main goal that must be develop together. The study will define the optimum mold cure time to speed-up lot processing and eventually increase machine open capacity while consider all risk to protect the product quality [6,7]. Gathering information on package volume vs the worldwide standard (WWS) where focus on mold process, Fig. 1 support and explain that the product VQFN-mR and QFN are the best choice to improve in terms of cost improvement.

Looking at the volume trend a gradual increase in projection (Fig. 2), although it is still covered by machine capacity, but a tight gap is seen which could affect production flow if there be uncontrollable event that will cause a delay in processing. The objective of this paper is to increase overall machine capacity of QFN/QFN-mR from 1548K/day to 2048k/day.

Another consideration is the flexibility of the machine to cater different types of packages just to support daily requirement and delivery [8-10]. During Package selection, QFN-mR and QFN utilizes its capacity, so to free-up a system for automotive packages we need to increase the capacity for transfer molding. In this case, QFN-mR have the least capacity of 485K/Day compared to QFN with 1063K/Day. As such, an increase in capacity might free-up some machine time that can utilize other packages at the same time shown on   Fig. 3.

1.1 Process Mapping

All steps that contributed the process cycle time was identified through process mapping. There are 10 major section on the transfer molding machine with 17 identified process steps that may considered for improvements.

1.2 Process Time Element

Understanding the mold process flow considering all the moving mechanism of molding machine, using time element study (Fig. 5) it shows that transfer mold cycle really dictates the processing time per lot as it accounts to around 63% of the total process time.

Deeper down to sub-steps of transfer mold cycle, using pareto (Fig. 6.) for each steps of cycle, *Mold Curing* have the longest time affecting the UPH at Transfer Molding Cycle and affects the other process steps causing longer queueing time.

What is Mold Curing? *Mold Curing* is the length of time to reach optimum viscosity or modulus of the material at a certain temperature. Curing is important to ensure product durability to protect it from external forces shown in Fig. 7.
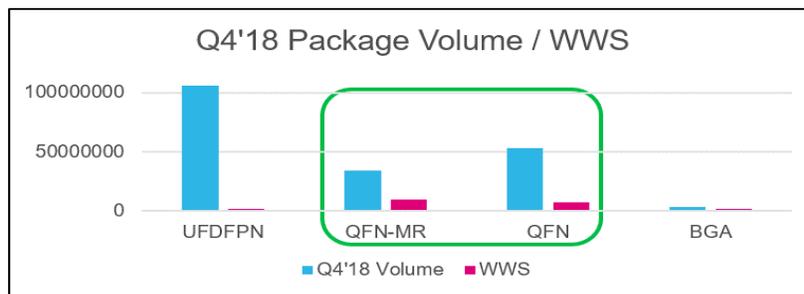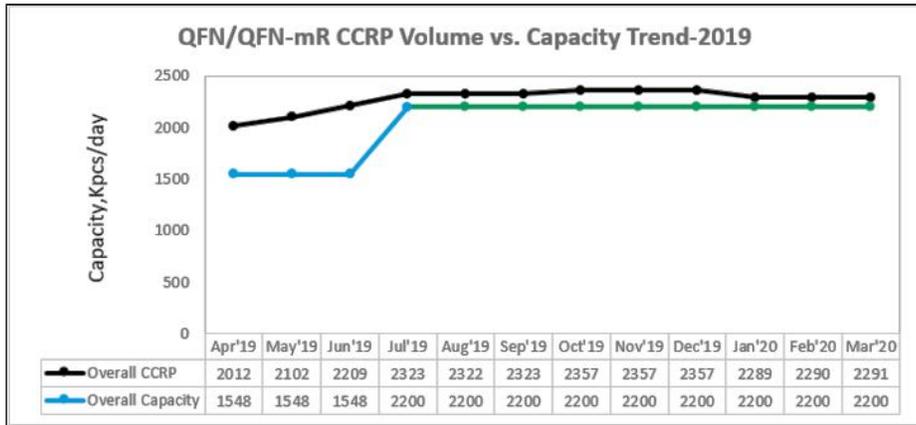

Fig. 1. Package volume vs WWS
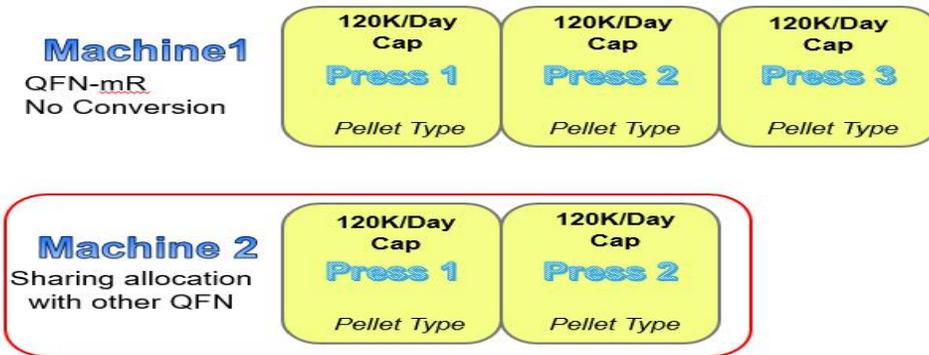
Fig. 2. Volume projection vs machine capacity
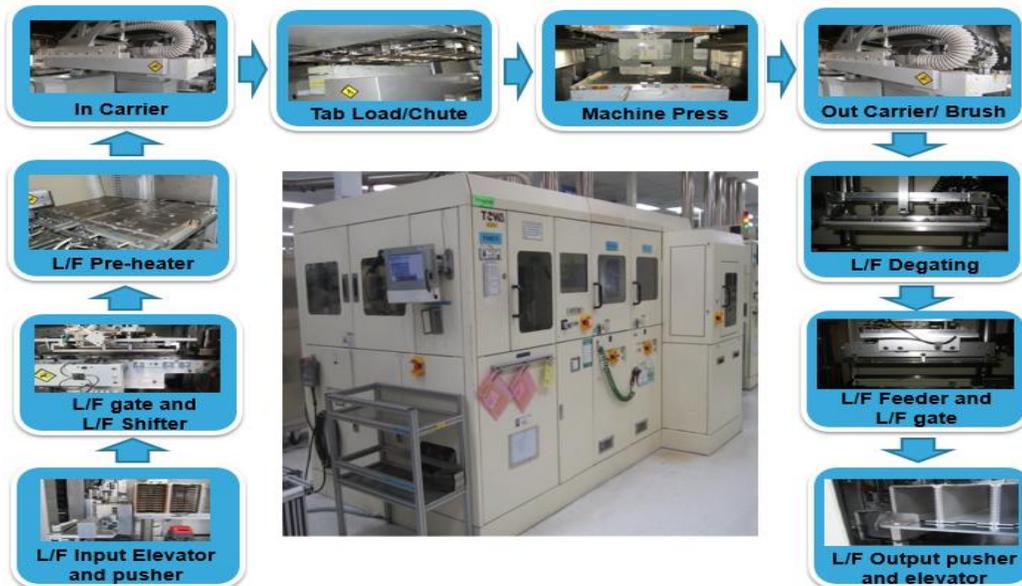

Fig. 3. Machine flexibility

Fig. 4. 10 Major process steps
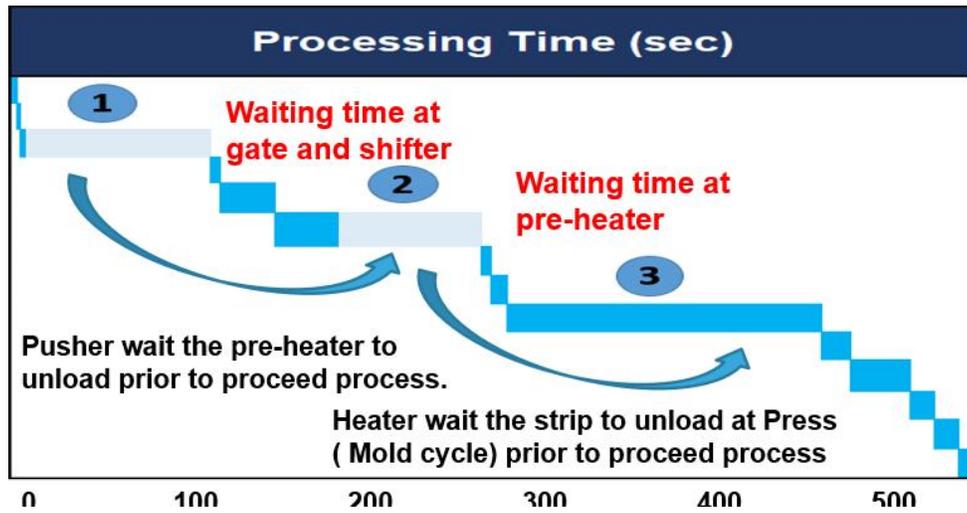
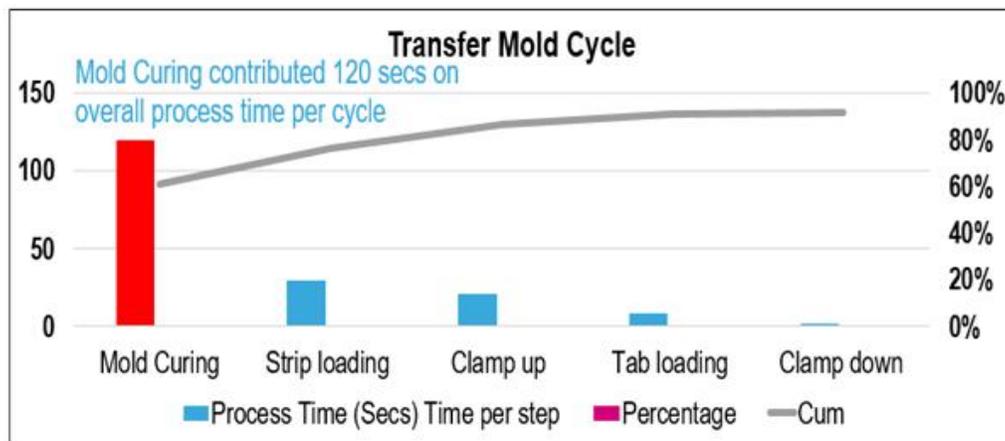**Fig. 5. Mold processing time element**

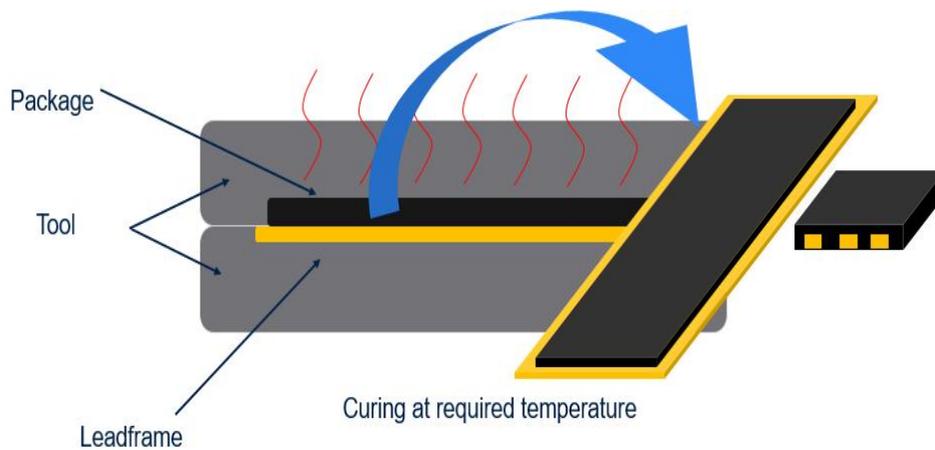

Fig. 6. Transfer Mold Cycle Pareto

Fig. 7. Mold curing

2. METHODOLOGY

2.1 Cure Ratio Study

Mold curing time is the core of the process and it not easy to change without knowing the capability of the material that is used to the product. A Curability Curve was requested to our supplier to get the minimum hot hardness of the compound.

Based on the study, the acceptable minimum hot harness was 75% cured. Fig. 8 shows 68 to 70 sec cure time will meet the required hot hardness and at min 80 secs was the proposed cure time to insure the minimum hot hardness will achieve. To re-enforce the data of proposed 80 secs cure time, a Different Scanning Calorimetry (DSC) was conducted to show the optimum curing. Three sets of curing time were study to realize differences of each timing. 120 secs, 90 secs and 80 secs undergone the measurement. Fig. 9 describe at 80 secs cure time, package was 95.7% cured and comparable to standard 120secs.

2.2 Risk Assessment

Conducted Quality Risk Assessment (Table 1) to consider all the possible risk for transfer molding prior the experiment. Risk identified was delamination, package sticking, crumpled strip, warp strip, package crack, package sticking, mold yield issues and reliability issues. Given considered actions on all identified risk for further validation during experimental run.

During selection, Mold Curing time have the highest impact to machine UPH and rated as class B(Major) during risk assessment. Sensitivity of the product was priority to ensure quality output. Table 2, shown that Device G selected as the device vehicle based on the sensitivity vs volume.

Using Force Field Analysis with ideal state to reduce mold curing time (Table 3), we identified 5 drivers for change and 3 restrainers. Driver for change is to improve overall capacity enable to free-up machine while reducing the time conversion and avoiding additional investments. Quality issue on moldability, reliability and may affect the production yield are the identified restraining forces.

2.3 Quick Wins

During identification and understanding improvements for transfer mold, we also identified quick solution for some delays on the machine shown on Table 4 that gain 6% on Machine1 and 3% on machine 2 improvements.

3. RESULTS AND DISCUSSION

3.1 Validation Plan

Generated validation plan to consider all risk identified during Quality Risk Assessment. See Tables 5 and 5.1.

3.2 Delamination Validation

Using 2 Proportional Test at 95% confidence level, there is no significant difference in terms of delamination between 80secs and 120 secs. Fig. 10 shows a good scat image result without any delamination and supported by statistical data on Fig. 10.1.

3.3 Package Sticking Validation

Machine, strip, and tool condition was considered during package sticking validation to ensure quality of the product. No package sticking, no sticking on tool and with good airvent bleed out shown on Fig. 11. Package Sticking validated at 95% confidence level using 2 proportion test (Fig. 11.1), there is no significant difference in terms of package sticking between 80 secs and 120 secs.

3.4 Crumpled Strip and Package Crack Validation

All moving mechanism of the machine was fully guarded and observed for crumpled and package crack during validation.

No crumpled and package crack during sample run. Moving mechanism and strip condition during validation shown in Fig. 12 -12.1.

Using 2 proportion Test (Fig. 12.2- 12.3), at 95% confidence level, there is no significant difference between 80secs and 120 secs cure time.

3.5 Strip Warpage Validation

Strip warpage also identified risk that considered to be validated. Using 10 cycles for both 80 secs and 120 secs, warpage measurements was both with normal distribution. See Fig. 13.

After measuring 10 cycles for each cycle, 80 secs warpage measurements are comparable with standard 120 secs (Fig. 14). Based on statistical results (Fig. 14.1-14.5), at 95%

confidence level, there is no significant difference in terms of warpage for both 80secs and 120 secs.

3.6 Reliability Validation

Submitted 3 sets of samples, 80 secs, 90 secs and 120 secs cure time. All sets passed Moisture Sensitivity Level Assessment (MSL) and Reliability Testing. See Table 6 and 6.1.

3.7 Validation Results

Based on validation, with all moldability and reliability Risk considered during experiment and the result is passing therefore Mold Curing time from 120 secs to 80 secs did not affected function or form of the product.

3.8 Implementation Results

Implementation results Table 7. passed all Assembly requirements and criteria on Moldability, Warpage, Scat, Wiresweep and Assembly Yield.

Test Response (Table 8) also considered and passed all Test Criteria and Limits. Passed on all electrical requirements and finish scanning.

Project gains 37% Capacity impact for VQFN-mr and open-up 2 system for QFN resulting not to purchase new equipment. Conversion and sharing of machine allocation were eliminated after project implementation. A total of 68% improvement for overall transfer molding capacity Fig. 14.5.
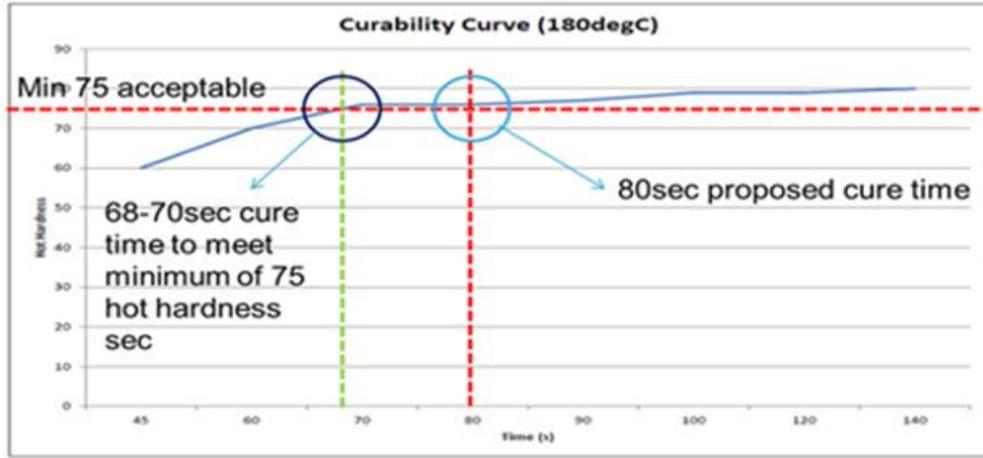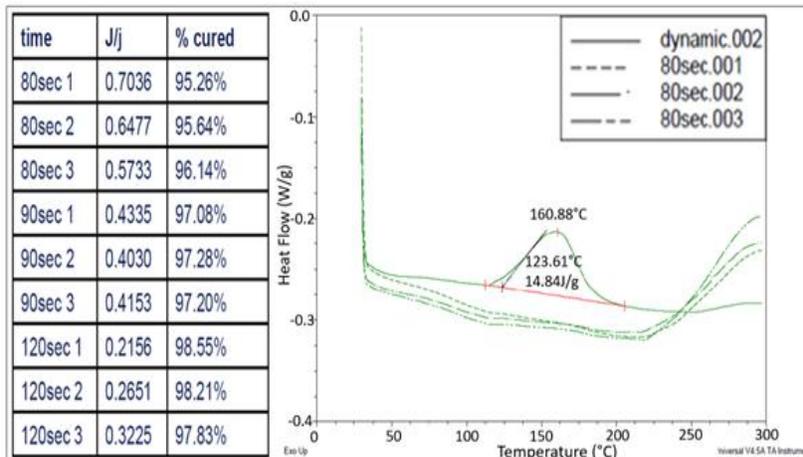

Fig. 8. Curability study from supplier

Fig. 9. Differential scanning calorimetry

Table 1. Quality risk assessment

No.	Risks Identified	Potential Risk Result from	Before Action		
			Prob.	Impact	Class
1	Delamination	Due to under cure package	3	3	B
2	Package Sticking	Due to under cure package	3	3	B
3	Crumpled Strip	Due to under cure package	3	3	B
4	Warp Strip	Due to under cure package	3	3	B
5	Package Crack	Due to under cure package	3	3	B
6	Package Chip-out	Due to under cure package	3	3	B
7	Mold Yield	Due to under cure package	3	3	B
8	Reliability	Due to under cure package	3	9	A
Maximum of [Prob. X Impact]			27		*A*

Table 2. Device vehicle selection

Package Desc/Code	Device Criticality/ Sensitivity	Per Device Volume
Device A		
Device B		
Device C		
Device D		
Device E		
Device F		
Device G	Sensitive	5828098
Device H		
Device I	Sensitive	No volume
Device J		
Device K		
Device L	Sensitive	407396

Table 3.

Ideal State: Reduction of Mold Curing Time	
Driver forces	**Restraining forces**
*To improves overall QFN capacity.	*Will cause Moldability Issue.
*To free-up machine for Automotive Readiness	*Will cause Reliability Issue.
*To meet the demand.	*Will cause Mold Yield Issue
*No investment for additional machine	
*No lost cap due to conversion	

Table 4. Quick win solution

Process Step	Findings	Correction/Action	Results
Preheater	Preheater time difference for both machine FAM076- 40 secs FAM078- 30 secs	Adjusted FAM076 pre-heater time to 30 secs	Running @ 30 secs preheating time
Preheater	Preheater PnP time difference for both machine FAM076- 7 secs FAM078- 5 secs	Adjusted FAM076 pre-heater PnP time to 5 secs	Running @ 5 secs preheating PnP time
Degating	Cull Cooling Time1 difference for both machine FAM076- 5 secs FAM078- 3 secs	Adjusted FAM076 Cull Cooling Time1 to 3 secs	Running @ 3 secs Cull Cooling Time1
Degating	Cull Cooling Time2 difference for both machine FAM076- 23 secs FAM078- 21secs	Adjusted FAM076 Cull Cooling Time2 to 21 secs	Running @ 21 secs Cull Cooling Time2
IN Gating	Observed inconsistent time at strip pusher for FAM078. Notice erratic movement during pushing. Min 4secs and max 30secs per strip	Adjusted roller pressure for smooth entrance of strip.	4secs strip pushing until gate stopper

Table 5. Validation plan level of X and Y

Validation Plan					
Y (or mini Y)	Unit of Measure	Y treated as	X	True nature of X	Levels of X
1.Delam	visual	discrete	Mold Cycle (transfer mold cure time)	Discrete	Slow:120 secs Fasrt:80 secs
2.Package Sticking	visual	discrete	Mold Cycle (transfer mold cure time)	Discrete	Slow:120 secs Fasrt:80 secs
3.Crumpled Strip	visual	discrete	Mold Cycle (transfer mold cure time)	Discrete	Slow:120 secs Fasrt:80 secs
4.Warp Strip	um	continuous	Mold Cycle (transfer mold cure time)	Discrete	Slow:120 secs Fasrt:80 secs
5.Package Crack	visual	discrete	Mold Cycle (transfer mold cure time)	Discrete	Slow:120 secs Fasrt:80 secs
6.Package Chip-out	visual	discrete	Mold Cycle (transfer mold cure time)	Discrete	Slow:120 secs Fasrt:80 secs

Table 5.1. Validation plan hypothesis statement

			Validation Plan			
	Hypothesis Statement		Graphical Analysis	Statistical Test	Beta	Alpha
Y	Null Hypothesis	Alternative Hypothesis				
1	$H_o: P_{Slow}=P_{Fast}$	$H_a: P_{Slow} \neq P_{Fast}$	Mosaic Plot	2-Proportion Test	0.1	0.05
2	$H_o: P_{Slow}=P_{Fast}$	$H_a: P_{Slow} \neq P_{Fast}$	Mosaic Plot	2-Proportion Test	0.1	0.05
3	$H_o: P_{Slow}=P_{Fast}$	$H_a: P_{Slow} \neq P_{Fast}$	Mosaic Plot	2-Proportion Test	0.1	0.05
4	$H_o: \mu_{Slow}=\mu_{Fast}$	$H_a: \mu_{Slow} \neq \mu_{Fast}$	Oneway Anova	2-Sample T- Test	0.1	0.05
5	$H_o: P_{Slow}=P_{Fast}$	$H_a: P_{Slow} \neq P_{Fast}$	Mosaic Plot	2-Proportion Test	0.1	0.05
6	$H_o: P_{Slow}=P_{Fast}$	$H_a: P_{Slow} \neq P_{Fast}$	Mosaic Plot	2-Proportion Test	0.1	0.05

Table 6. Moisture sensitivity level results

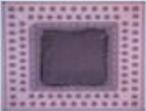| Mold Cure Time	80 sec	90 sec	120 sec
MSL Result	Passed Level 3	Passed Level 3	Passed Level 3

Conclusion:
• This package passed Level 3, 260°C Pb-Free convection reflow temperature.
  • Dry Bag required.
    - 168 hours out of bag Floor Life at maximum ambient ≤30°C/60%RH.

Table 6.1. Reliability results

Reliability Trial	Reduce Mold Cure time from 120 secs to 80secs	Reduce Mold Cure time from 120 secs to 90secs	120 Control (existing condition)
SAM	Done (refer to slide 7)	Done (refer to slide 10)	Done (refer to slide 12)
MSL3	Done	Done	Done
ATE	0/80 All passed	0/80 All passed	0/80 All passed
SAM	Done(refer to silde 7)	Done (refer to silde 10)	Done (refer to slide 12)
500cy	Done	Done	Done
ATE	0/80 All passed	0/80 All passed	0/80 All passed
SAM	Done (refer to slide 8)	Done (refer to slide 11)	Done (refer to slide 13)
1000cy	Done	Done	Done
ATE	0/80 All passed	0/80 All passed	0/80 All passed
SAM	Done (refer to slide 9)	Done (refer to slide 11)	Done (refer to slide 13)
MSL3	Done	Done	Done
ATE	0/80 All passed	0/80 All passed	0/80 All passed
96h + LEAD CLEANING	Done	Done	Done
ATE	0/80 All passed	0/80 All passed	0/80 All passed
500h	Done	Done	Done
ATE	0/80 All passed	0/80 All passed	0/80 All passed
1000h	Done	Done	Done
ATE	0/80 All passed	0/80 All passed	0/80 All passed

Table 7. Assembly results

Scat Image	X-ray Result (Wire sweep %)	Remarks
No Voids/ Delam	3.61%	Passed

Lot #	Moldabilty	Warpage -/+ 700um	Scat	Wiresweep (%)	Mold Yield	Overall Assy Yield	Overall Result
1	Passed	322.3	Passed	4.63	99.89%	99.72%	Passed
2	Passed	423.1	Passed	4.51	100%	99.92%	Passed
3	Passed	366.1	Passed	6.38	100%	99.30%	Passed
4	Passed	371.5	Passed	7.55	100%	99.13%	Passed
5	Passed	338.1	Passed	7.01	100%	98.50%	Passed
6	Passed	344.2	Passed	3.61	100%	99.15%	Passed
7	Passed	334.0	Passed	4.12	100%	99.80%	Passed
8	Passed	322.2	Passed	7.08	100%	99.45%	Passed
9	Passed	315.3	Passed	6.25	100%	99.47%	Passed
10	Passed	286.7	Passed	4.00	100%	98.86%	Passed

Table 8. Test results

# of lots	Remarks	YIELD	SBL	QA	Status
5	Linestressing lots	97.96%	Passed	Passed	Closed
2	Linestressing lots				
3	Linestressing lots				
8	Linestressing lots				
7	Linestressing lots	97.69%	Passed	Passed	Closed
1	Linestressing lots				
4	Linestressing lots				
6	Linestressing lots				
9	Linestressing lots	98.29%	Passed	Passed	Closed
10	Linestressing lots	98.38%	Passed	Passed	Closed
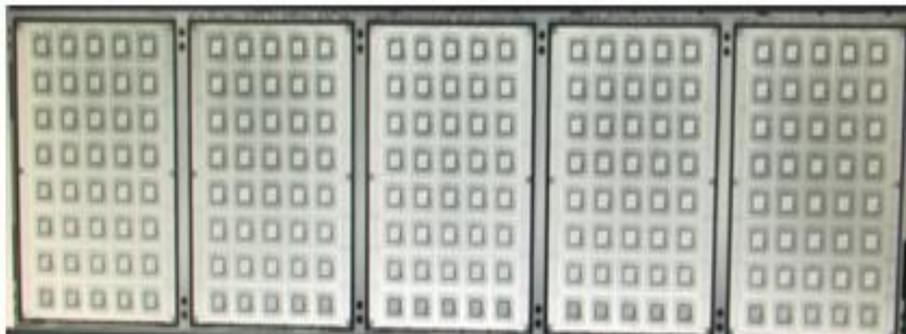
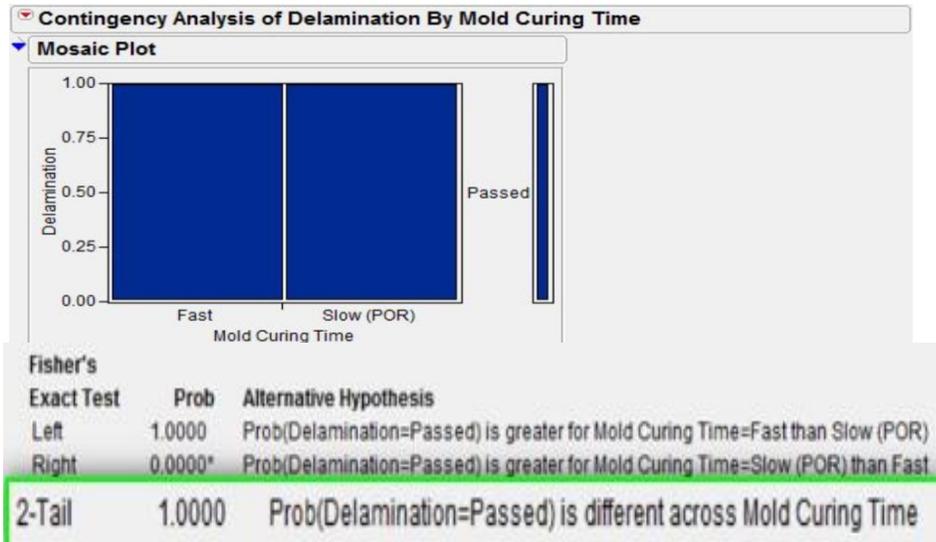**Fig. 10. Scat image result**

Fig. 10.1. Proportion test for delamination

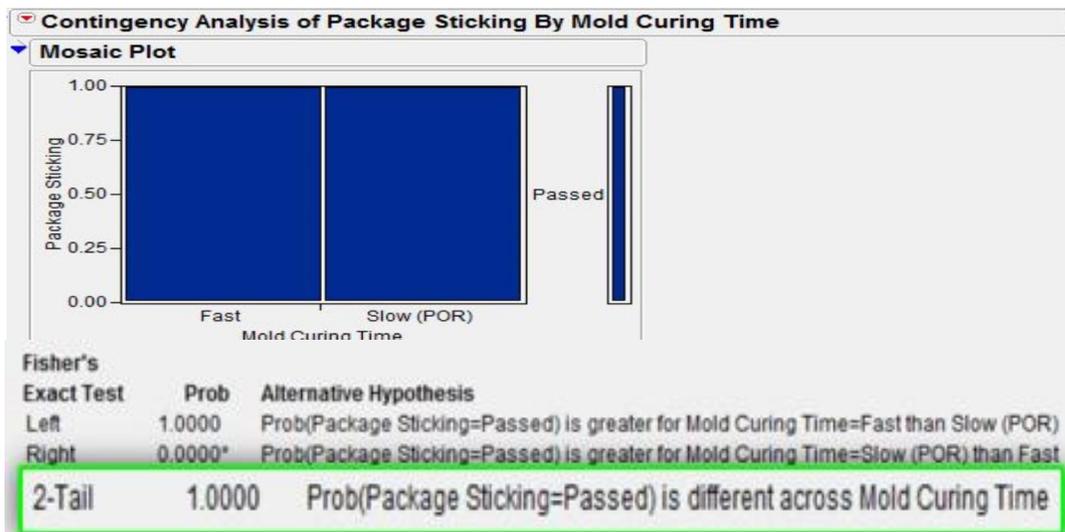**Fig. 11. Strip condition for package sticking validation**

Fig. 11.1. Proportion test for package sticking

Fig. 12. Moving mechanism and strip condition during crumpled validation
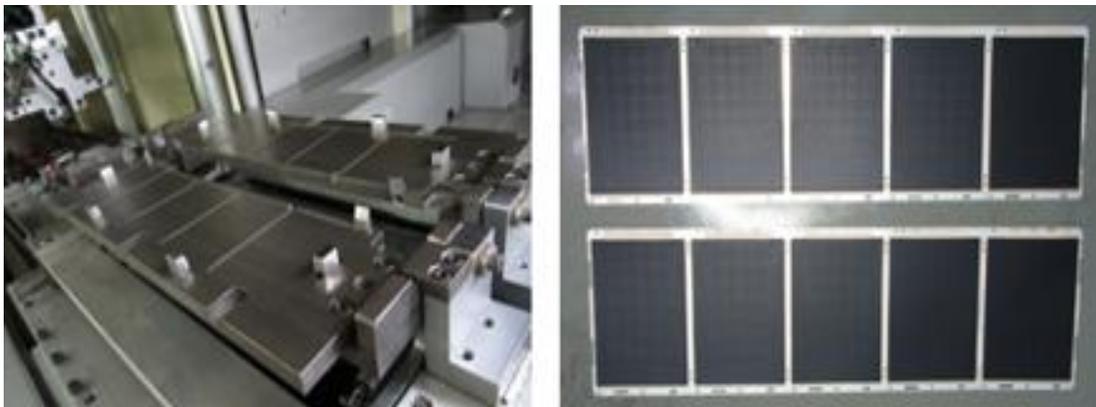

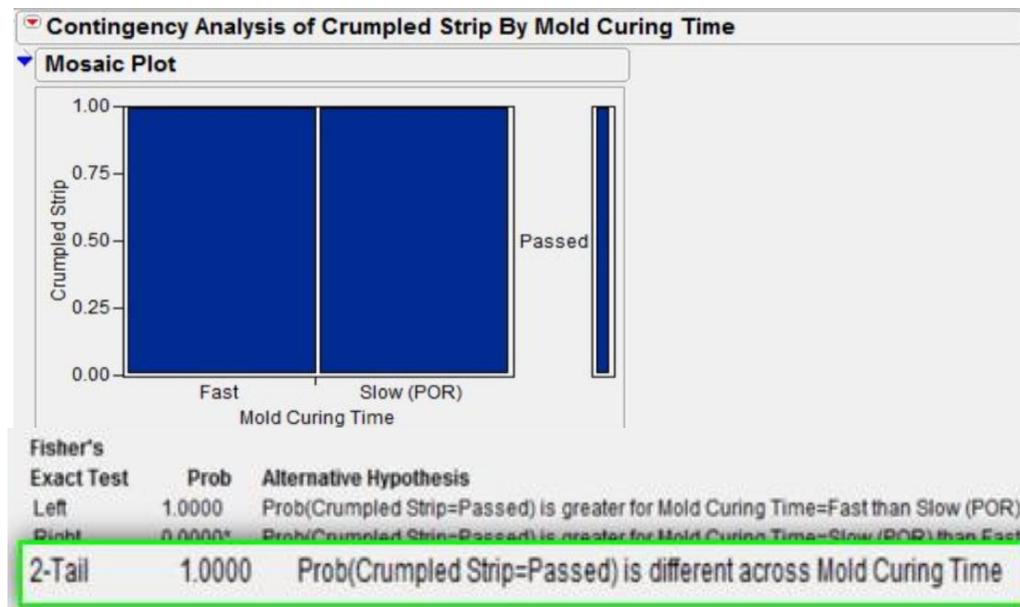**Fig. 12.1. Moving mechanism and strip condition during package crack validation**

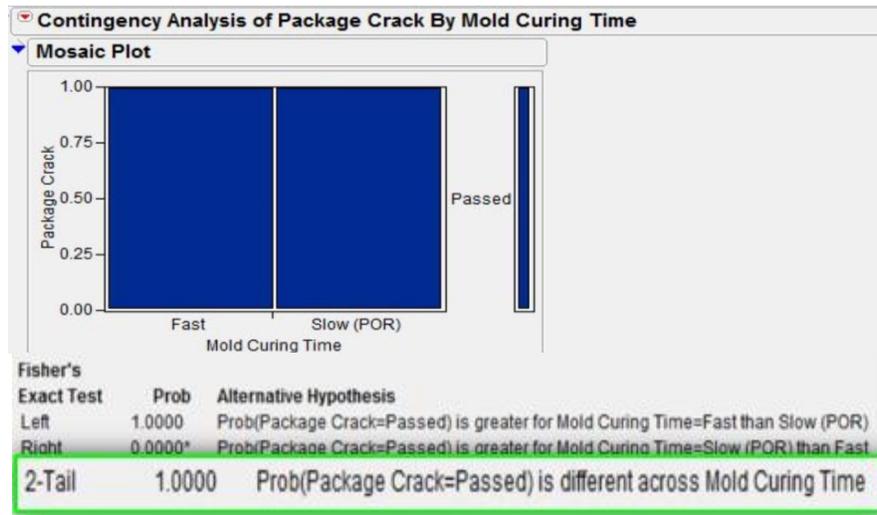

Fig. 12.2. Proportion test for crumpled strip

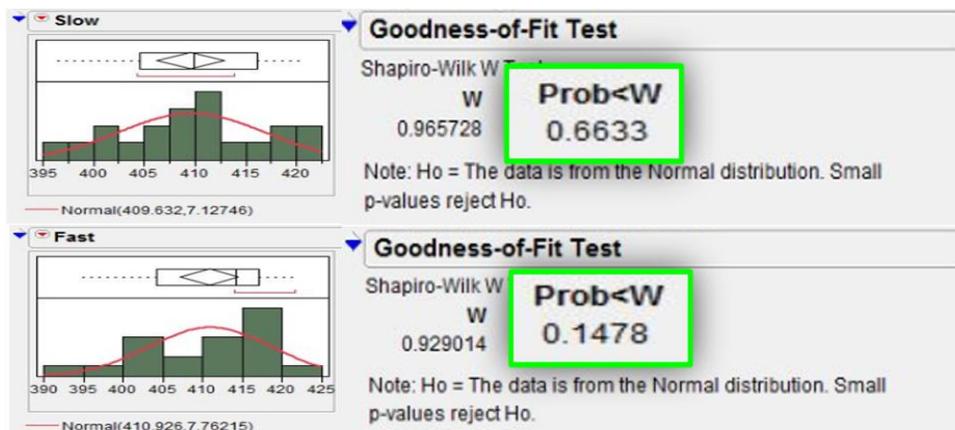**Fig. 12.3. Proportion test for package crack**

Fig. 13. Normal distribution of 80 secs and 120 secs cure time
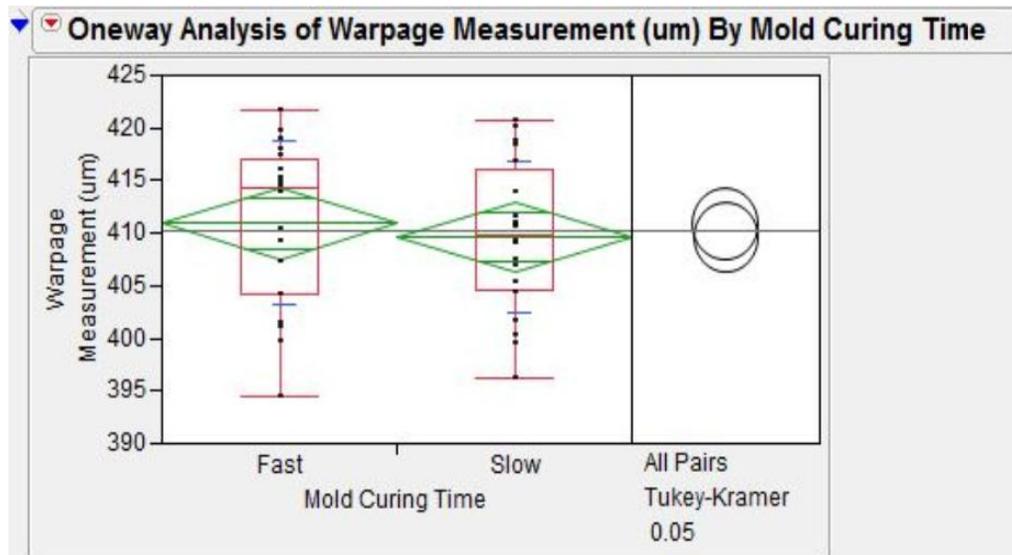

Fig. 14. Actual strip warpage condition

Fig. 14.1. Warpage measurement oneway analysis

Fig. 14.2. Analysis of Variance
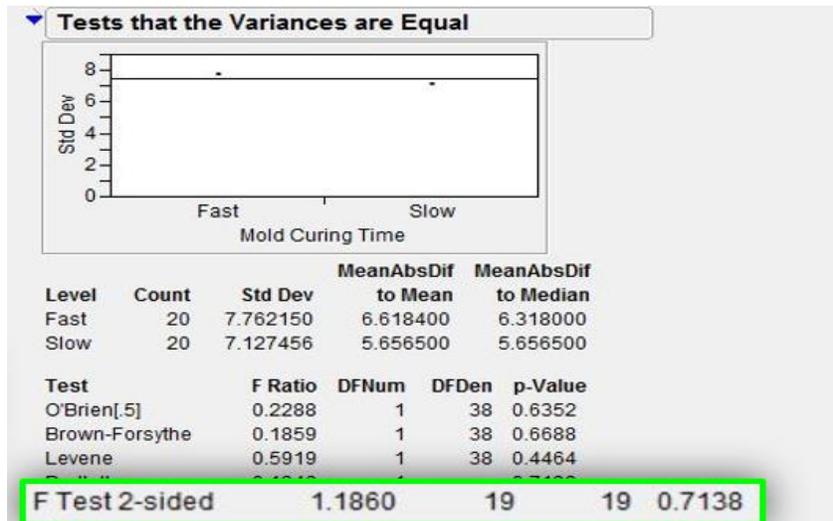

Fig. 14.3. Means comparisons

Fig. 14.4. Statistical analysis for strip warpage

Fig. 14.5. Statistical analysis for strip warpage

3.9 Documentation

Documented all activities and deployed to shopfloor personnel.

No.	Action Item	Remarks
1	PCMS	Done
	Included Linestressing Results, Risk Assessment, REL result	
	Document Change Plan of Curing time from 120 secs to 80 secs	
2	Work Instruction	Done
	Updated parameter matrix for VQFN-mR	
3	Deployment	Done

3.10. Future Plan

Success of the project will be fan-out to other machines and other packages.

Action to Implement	Improvement	Remarks
Fan-out to other machines	Capacity Improvement	Done
Fan-out to other thinner packages	Capacity Improvement	Ongoing data gathering

4. CONCLUSION

Based on all validation with the used of DSC, Curability Curve, Statistical Validation and Actual lot runs, with all the Moldability, Test and Reliability risk considered during run and result is passing, therefore, it is validated that reduce in mold curing time from 120secs to 80secs did not affect Form, Fit and Function of the vehicle product. Reducing cure time improves overall capacity of transfer molding.

5. RECOMMENDATIONS

A thorough material testing and analysis are the key to understand the material capability and be able to define its optimum curing time. Passing all validation and considered all the risk identified, it now recommended to implement Mold Curing Time at 80 secs. An ongoing fan-out to BGA packages

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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