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Compound Handling Automation: An Error Proof Solution in Eliminating Mold Misprocessing

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Authors' contributions

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

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ABSTRACT

This paper aims to identify and eliminate the weaknesses of the epoxy mold compound (EMC) thawing process that contributes to mold misprocessing occurrence such as wrong mold compound, under thawed or expired mold compound.

Creation of automation solutions addressing high risk areas such as barcoding of compound traceability, auto-locking system of thawing cabinet and thawing room access, automated map of compound status and upgrade of lot transaction system to link with EMC status and identity was implemented. Collectively this makes the process error proof from wrong judgement or negligence from human dependent activities.

The project was able to eliminate occurrence of possible mold misprocessing related to EMC thawing and serves as cost avoidance due to potential lots affected.

Keywords: Epoxy mold compound; material handling; automation; thawing.

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1. INTRODUCTION

Thawing is an important step in the EMC preparation prior to molding process. It prevents deterioration of the mold compound properties and performance to attain good quality and reliable products in integrated circuit (IC) manufacturing. EMC is sensitive to environment condition that affects its degree of curing.

There is typically four stages in the curing of EMC, thawing is considered the end part of stage B after cold storage condition in transportation from EMC manufacturer to warehouse as shown in Fig. 1.

To perform thawing, EMC is withdrawn from cold storage with temperature of 5°C or below and undergoes a staging process typically 24 hours under room temperature with specification of 23°C ± 3° (Alert: 21°C to 24°C) and relative humidity 40 to 55 %RH (Alert: 41% to 51%) as shown in Fig. 2. Afterwards EMC is now available for use in molding based on its defined floor life. Once floor life is used up, EMC is considered expired and should be disposed properly. The main purpose of thawing is to prevent moisture from coming the package. If not removed this will result to mold defects like package voids, blister or incomplete. Moisture can also cause reliability problems like bond pad or wire corrosion, delamination or pop-corn effect when heat is applied in post assembly or customer processes.

1.1 Mold Compound Misprocessing

Misprocessing at mold related EMC handling includes wrong EMC, expired EMC and under thaw EMC. Wrong EMC is defined as the use a different EMC against the product requirement which can either be wrong type or wrong pellet size. Expired EMC is the use of the material beyond its defined floor life. Under thawed EMC is when material was used when thawing time is not yet complete.

Based from the EMC misprocessing trend, one misprocessing occurrence was recorded for expired EMC in Q4'18 and one occurrence in Q1'19 due to under thaw as shown in Fig. 3.

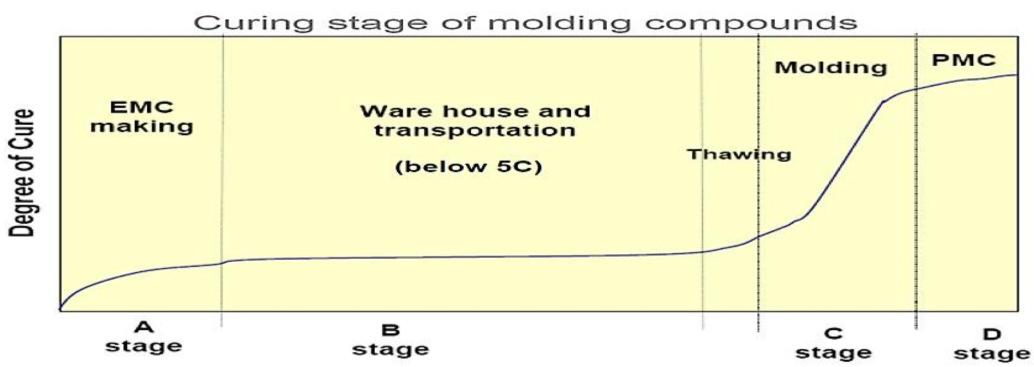


Fig. 1. Four curing stages of EMC

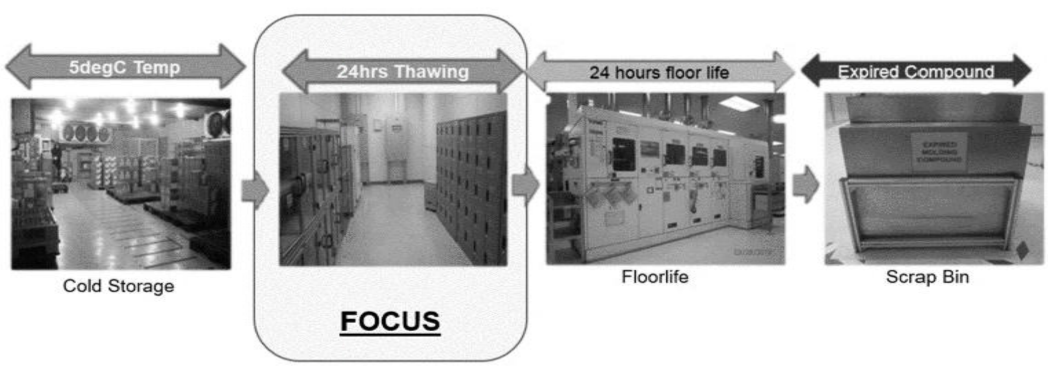


Fig. 2. Mold compound handling process flow

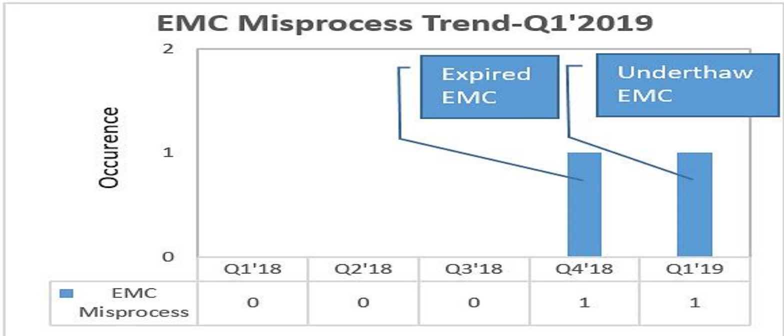


Fig. 3. Mold compound misprocessing trend as of Q1'2019

Misprocessing due to compound mishandling were subjected to reliability test and results show delamination on top of die and die paddle area as shown in Fig. 4. All lots affected are scrapped to avoid customer complaint.

1.2 Current Mold Compound Misprocessing Controls

Previous controls to prevent misprocessing of EMC includes the use of unique color assignments of pellet/granule identification form per EMC type and size as shown in Table 1.

The color coded pellet/granule identification form as shown in Fig. 5 is filled up to indicate the mold machine number allocation, compound type, pellet/granule size, compound 8NC, lot no., package type which are critical information to prevent wrong EMC used. Also included in the filled up items are the withdraw start, withdrawal end and expiration end date and time. These items are key to identify if compound is under thawed or expired already. This small form is attached to the molding compound bags or container by the use of a tape inside the thawing area.

Table 1. Pellet/ Granule color code matrix

Color Code	EMC description	Size	Package	EMC material code
Cyber pink	Compound A	16 mm/12.5 g	VFDFPN8	5ST97516
Cyber green		16 mm/7.7 g	THUQFN76/HUQFN88/UFDFPN8	5ST00641
Cosmic Orange		16 mm/11 g	HVQFN/THUQFN76/HUQFN88	5ST09531
Orange		16 mm/9.5 g	VFDFPN12/UFQFPN48	5ST07832
Aqua	Compound B	16 mm/10.8 g	VFDFPN12/UFQFPN48	5ST29209
Peach		16 mm/11.8 g	WPLGA88	5ST97226
Gray			VPLGA88/VFQFN48-2D	5ST97227
Cyber Orange	Compound C	14 mm/6.3 g	LFBGA273	5ST07978
Turquoise		14 mm/7.3 g	HWQFN48R/56, TFBGA36/48/135/141, LFBGA49,uTFBGA25, VFBGA48/100	5ST00111
Light Pink	Compound D	14 mm/7.3g	TFBGA169/240/388, LFBGA296/240/340	5ST97038
Ivory	Compound E	14 mm/7.3g	HTQFN/HVQFN40-06/ TFBGA44/88, HWQFN56	5ST00261
Cyber Yellow	Compound F	14 mm/6.3g	LFBGA273	5ST18563
Gamma Green	Compound G	0.15-1.0	SCALPAK	5ST18591
Green	Compound H	0.15-2.0	MEMS/COL	5ST18423

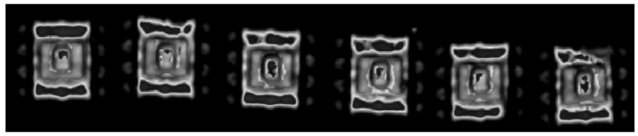


Fig. 4. SAM image of under thaw after reliability test

At mold process, EMC details which include material code, lot no. expiration date of floor life and shelf life are recorded by mold operator on mold monitoring log sheet every start of the shift and after EMC replacement as shown in Fig. 6.

1.3 Automation of the Thawing Process

Controls to prevent misprocessing of mold compound are human dependent and are susceptible to errors in filling up the pellet/granule identification form. Mishandling of these forms can lead to swapping or missing and can be aggravated by negligence or discipline issue on the part of personnel using the material that is known to be under thaw or expired.

A detailed process mapping at thawing was conducted to identify the weaknesses of the current controls to prevent misprocessing. Based from these weaknesses, automation solutions will be created to error proof the process from

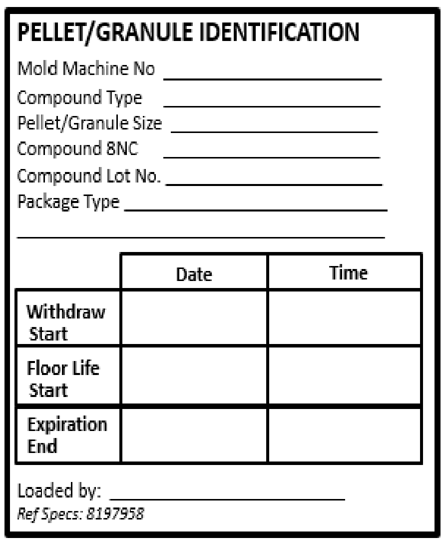
Table 2. EMC handling process mapping

EMC handling sub-process	**Failure mode**	**Potential cause**	**Process weakness**
Withdrawal from cold storage	Expired shelf life	None - warehouse system blocks expired shelf life	None
Pellet/granule ID generation	Wrong EMC, Under thaw, Expired	Error in fill-up of EMC info	Manual fill-up of info
		Swap ID during attachment	Poor attachment to packaging, ID form attached using tape
		Lost or fallen ID	
EMC Thawing on cabinet	Wrong EMC, Under thaw, Expired	Swap ID during attachment	Poor attachment to packaging, ID form attached using tape
		Lost or fallen ID	
		Unintentional pull-out of EMC from cabinet	EMC not secured during thawing period
			Weak area ownership
			Poor visibility of compound status
MC for production use	Wrong EMC	Swap ID during attachment	Poor attachment to packaging, ID form attached using tape
		Lost or fallen ID	
		Swap lot or wrong lot loaded	Lot to EMC cross check not per lot, Human dependent activity
		EMC failed dumping after conversion	Human dependent activity
	Under thaw, Expired EMC	Unintentional pull-out of EMC from cabinet	Human dependent activity
EMC Replacement	Wrong Expired EMC	Failure to dump expired or different	Human dependent activity
EMC handling sub-process	Failure Mode	Potential Cause	Process Weakness
Withdrawal from cold storage	Expired shelf life	None - warehouse system blocks expired shelf life	None
Pellet/granule ID generation	Wrong EMC, Under thaw, Expired	Error in fill-up of EMC info	Manual fill-up of info

human mistake or non-compliance. The automation project will prevent manual fill-up of the pellet/granule identification form by requiring EMC suppliers to upgrade their packaging labels with barcode and making a system to electronically print these labels in stickers. A solution to prevent production personnel from physically taking out material/s that are still undergoing thawing or are expired for disposal is to create an auto-locking thawing cabinet which will not open unless it has completed its thawing. To control the personnel inside the thawing room, an access pass on authorized personnel only is necessary. To have better management of the status of the compound at thawing room an electronic map of the thawing cabinets will be helpful. In manufacturing floor, there should be a system to stop production to process a lot if the compound is wrong, under thaw or expired. Summary of EMC handling process mapping are itemized in Table 2.

1.4 Review of Related Literature

Inspired by Industry 4.0, the goal of Back-End Manufacturing and Technology (BEM&T) where ST Calamba belong is to develop a state-of-the-art manufacturing environment in the coming years. Since 2018, 43 projects have been identified and 22 are currently active. Industry 4.0 improves productivity and enables companies to remain competitive thanks to technological advances including robotics, big data analytics, Internet of Things (IOT) and traceability as shown in Fig. 7 which are pillars for this program.



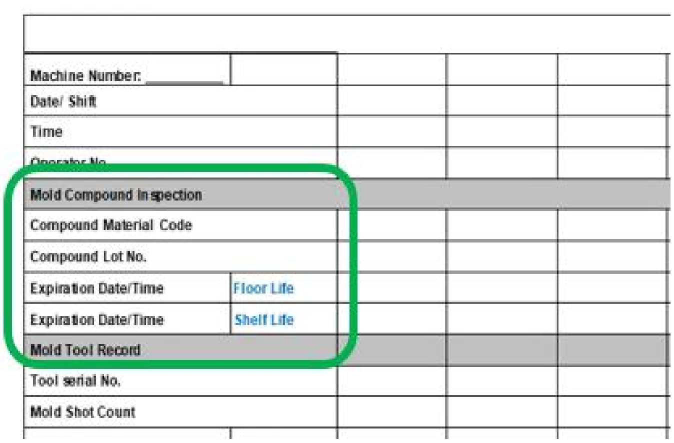
PELLET/GRANULE IDENTIFICATION

Mold Machine No ____________
Compound Type ____________
Pellet/Granule Size ____________
Compound 8NC ____________
Compound Lot No. ____________
Package Type ____________

	Date	Time
Withdraw Start		
Floor Life Start		
Expiration End		

Loaded by: ____________
Ref Specs: 8197958

Fig. 5. Pellet/granule identification form



Machine Number: ______				
Date/ Shift				
Time				
Operator No.				
Mold Compound Inspection				
Compound Material Code				
Compound Lot No.				
Expiration Date/Time Floor Life				
Expiration Date/Time Shelf Life				
Mold Tool Record				
Tool serial No.				
Mold Shot Count				

Fig. 6. Mold monitoring log sheet

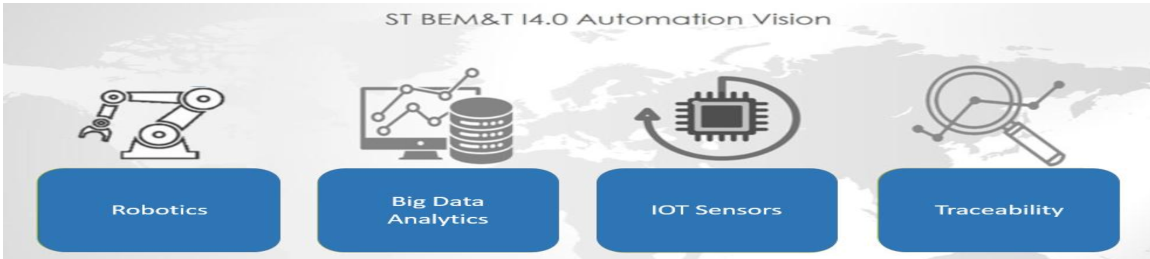


Fig. 7. ST BEM&T Automation vision

This paper is aligning with this vision and will demonstrate automation focusing on big data analytics, IOT sensors and traceability. One of the key solutions in eliminating misprocess is to eliminate manual encoding of information via barcode scanning. A research study below discusses about the evolution of material labeling.

Smart factories are defined as flexible and fully connected factories that are able to make use of constant streams of data from operations and production systems [1]. In such scenarios, the arguably most popular way for identifying and tracking objects is by adding labels or tags, which have evolved remarkably over the last years: from pure hand-written labels to barcodes, QR codes, and RFID tags.

There are several labeling technologies that can be used for the automatic identification of industrial products. The most basic is barcodes, which are basically a visual representation of the GTIN codes previously mentioned in Section I. Barcodes require Line-of-Sight (LoS) in order to read them correctly with barcode readers. In addition, they require a relative short reading distance (up to a few tens of centimeters). Nonetheless, they have been very useful in many industrial applications and have increased item identification speed remarkably respect to traditional manual identification procedures. Moreover, barcodes are really cheap and only require barcode generation software and a printer to start labeling objects. Although in the automatic identification scenario depicted by Industry 4.0 barcodes might seem to be unnecessary, they can still be useful in certain situations where reduced costs, short reading distances or very specific reading locations exist in an industrial scenario.

Bar and QR codes are usually applied in inventory applications, for tracking parts or in administrative procedures, but their reading distance is limited by the need for line-of-sight, they do not allow for interacting with items, and, obviously, they are not able to report actively on the state of the product they are attached to. Fig. 8 shows the evolution of labeling technologies until the arrival of smart labels.

Perishable material control system and mold compound control system has a database of all the EMC withdrawal information that is linked to the Manufacturing Execution system (MES). Cross check of MES to this system will aid decision making to proceed or not processing of lot. The auto-lock cabinet system sensors, actuators and hardware is controlled by the mold compound control systems' PLC.

The evolution of the automation hierarchy from the traditional pyramid concept to a cloud concept where all systems are interacting as shown in Fig. 9 [2].

As this paper works with the enhancement on our Manufacturing execution system (MES), FW2 system, it would be good to gauge our current system capabilities to what the industry outlook as to the future of a modern MES.

Modern Manufacturing Execution Systems (MES) based on decentralized logic offer a platform for the development of the Industry 4.0 model and a natural route to its vertical integration [3]. MES have always been most effective when integrated into Enterprise Resource Planning (ERP) systems 'above' while monitoring and controlling production processes 'below'. With the Cyber-physical Systems (CPS) and Cyber-physical Production Systems (CPPS) communicating directly with each other, the MES can trigger business rules or workflows for the complete production process. For example, quality processes may demand that a device may need additional verification steps before processing continues as part of a higher level quality sampling strategy. This requires

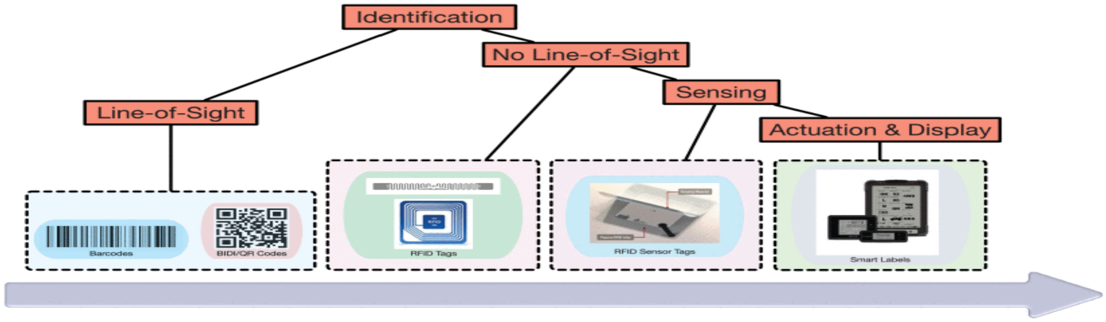


Fig. 8. Industrial labeling technology evolution

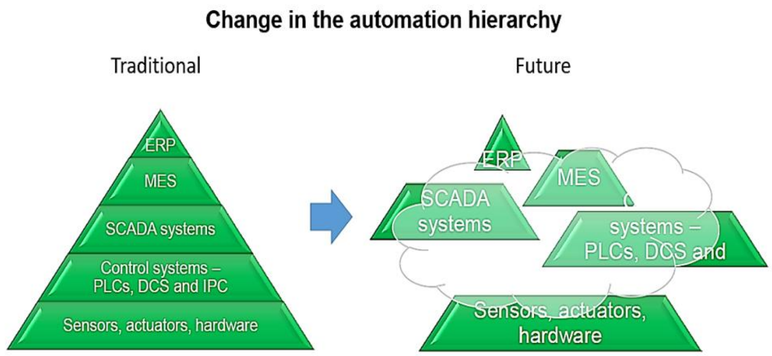


Fig. 9. Change in automation hierarchy

communication to intersect the business rules so the quality procedures are not bypassed before the device continues through its production processes.

Another area that is reliant on good vertical integration of systems within Industry 4.0 is Statistical Process Control (SPC). SPC requires data to be collected over time from numerous materials passing through the factory. For example, if a device within the CPS knows it needs to collect a measurable variable, this needs to be confirmed against SPC rules that it is within limits. If it is not, corrective action may be required. Flags for such actions need to be triggered in systems above the CPS and, again, the MES are an ideal platform for this.

In ST Calamba, this verification steps and SPC integration are already implemented in our FW2 system. The need to expand further integration to ensure correctness of the material used in the process and the timing it will be used will be crucial to prevent misprocessing. The details of how this paper will address this need will be discussing on the succeeding section.

2. MATERIALS AND METHODS

2.1 Materials

To automate pellet/granule identification, suppliers were asked to upgrade their packaging labels to include barcode equivalent of the information such us material description, part number, lot number, manufacturing date, expiration date, quantity and box number. Barcoded information needs a scanner to read the information and transfer it to a barcode printer to print information in prescribed format on the label sticker as shown in Fig. 10.

Production lot traceability known as runcard needs to have barcode information on the EMC requirement for cross checking with the EMC currently loaded during lot transaction. Same barcode format is used on runcard during molding as shown in Fig. 11.

2.1.1 Hardware

EMC thawing storage needs to be change from its open rack or cabinet configuration into a close cabinet type with built in lock system to prevent unintentional pull-out of EMC while still thawing or is already expired. Each location has an LED indicator to serve as visual control of its status shown in Fig.12.

To prevent unauthorized personnel inside the thawing area an access pass apparatus was installed for thawing room door opening as shown in Fig. 13.

2.1.2 Automation software and upgrades

To read EMC supplier label and print the pellet/granule identification form a software called perishable material control (PMC) was developed as shown in Fig. 14b. Part of the print-out is a unique code called box id which can be used as interface to other manufacturing system shown in Fig. 14c. There is also no more need for a logsheet for compound withdrawal as this is already done electronically. Manufacturing Management System (MES) uses Factory works 2 (FW2) system which was upgraded to integrate PMC data for cross checking as shown in Fig. 14a.

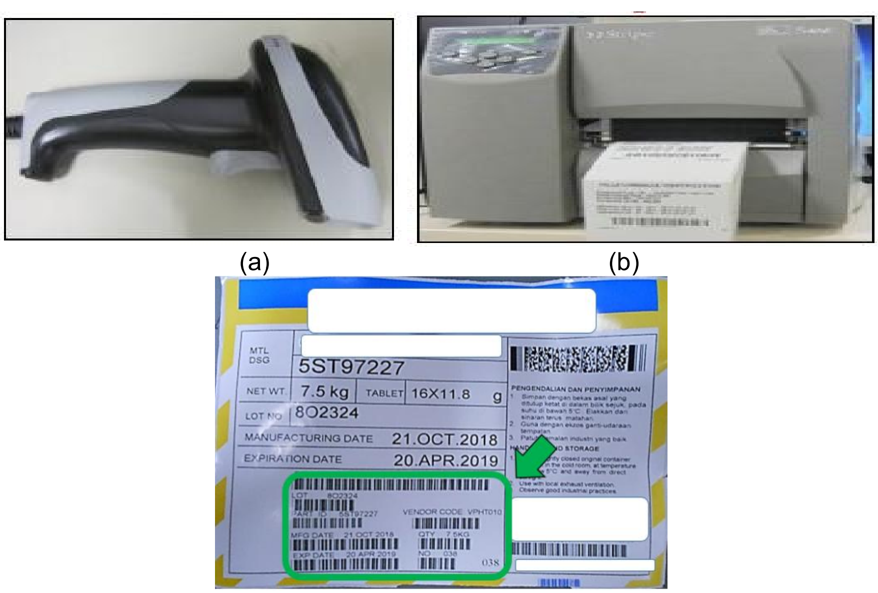
Another software that was developed was the mold compound cabinet monitoring application installed on the PC at thawing room as shown in Fig. 15. This will serve as the control system of the EMC at the automated thawing cabinet lock. EMC once completed thawing will automatically open its cabinet door lock. When compound is ready, a request is made via electronic withdrawal form. It also gives a visual map of the status and cabinet location of each compound loaded by user.

2.2 Procedure

With all of the needed materials, hardware and software in place a test run will be conducted to check the accuracy and the effectiveness of all the automations done as shown in Fig. 16.

For PMC barcode printing, printed label will be cross-checked if all the information scanned are correct against the mold compound label. All the transacted EMC in PMC will also be verified if registered in the electronic logsheet of EMC.

In mold compound cabinet control application, same counter-checking will be performed on barcode scanned data. Status and location at screen against actual condition at auto-lock cabinet will be verified. Accuracy of the cabinet opening will be verified if is compliant to the 24 hrs requirement. All the transacted EMC in the withdrawal form will also be verified if registered in the electronic withdrawal logsheet.



(c)

Fig. 10. a) Barcode scanner, b) Barcode printer and label sticker, c) Mold compound supplier label

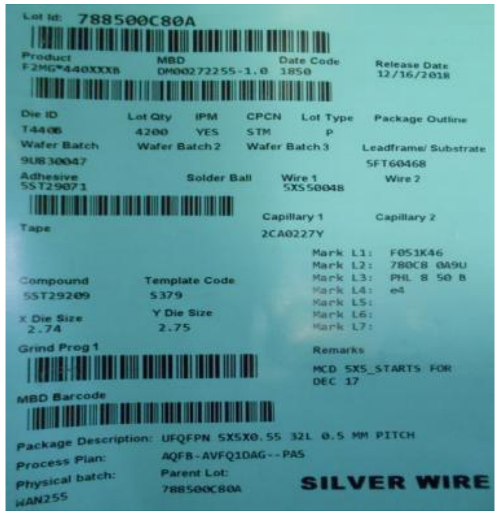
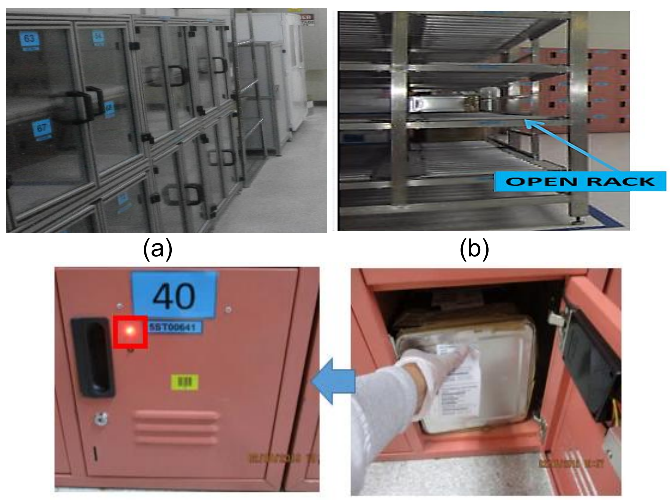


Fig. 11. Runcard used in ST Calamba



(a) (b)

(c)

Fig. 12. Thawing EMC storage (a) Open cabinet, (b) Open rack (c) Closed cabinet with lock system

Fig. 13. Access pass at thawing room

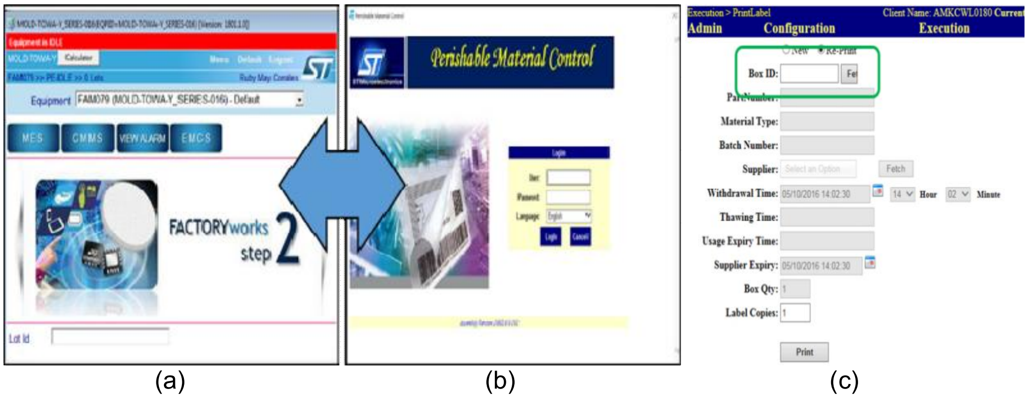


Fig. 14. (a) FW2 system, (b) Perishable material control, (c) Print label screen inside PMC

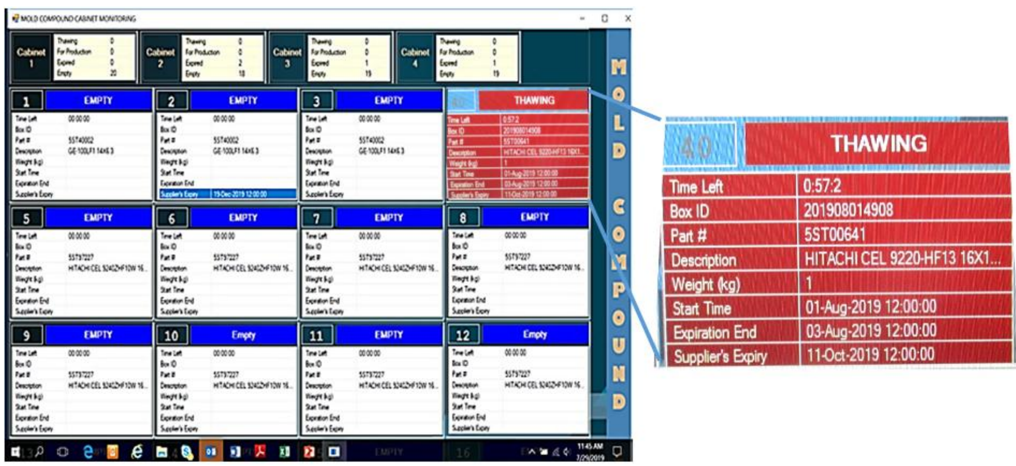


Fig. 15. Mold compound cabinet monitoring system

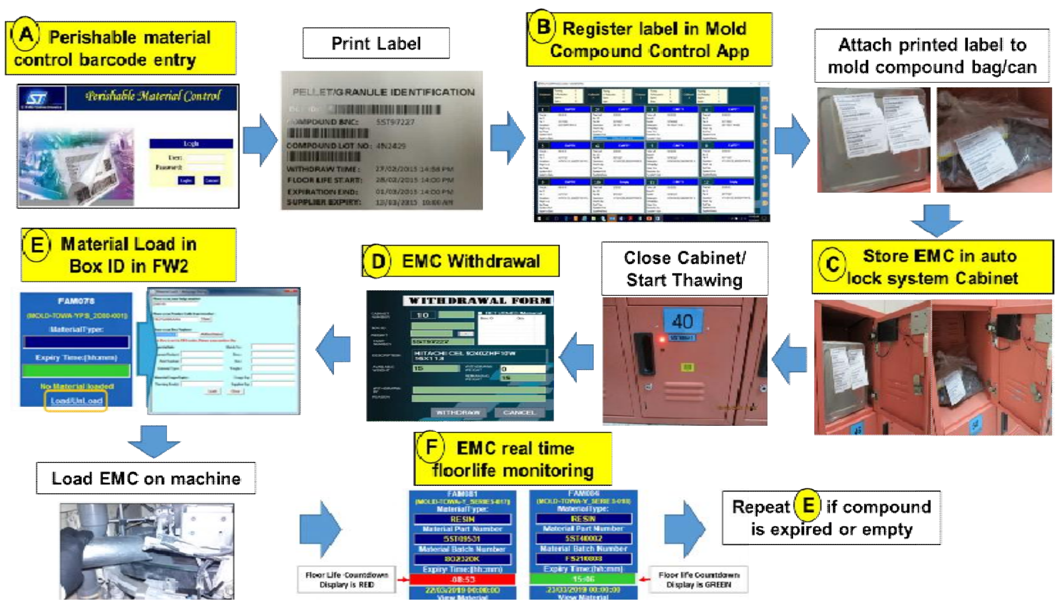


Fig. 16. EMC handling process automation flow

Upgrade of the FW2 system will be checked if wrong production lot will encounter error in track-in after material load of the pellet/granule identification box id was registered. Verification will be performed if system will pre-alert personnel that material will expire and that the production lot track-in will be disabled when compound is already expired.

3. RESULTS AND DISCUSSION

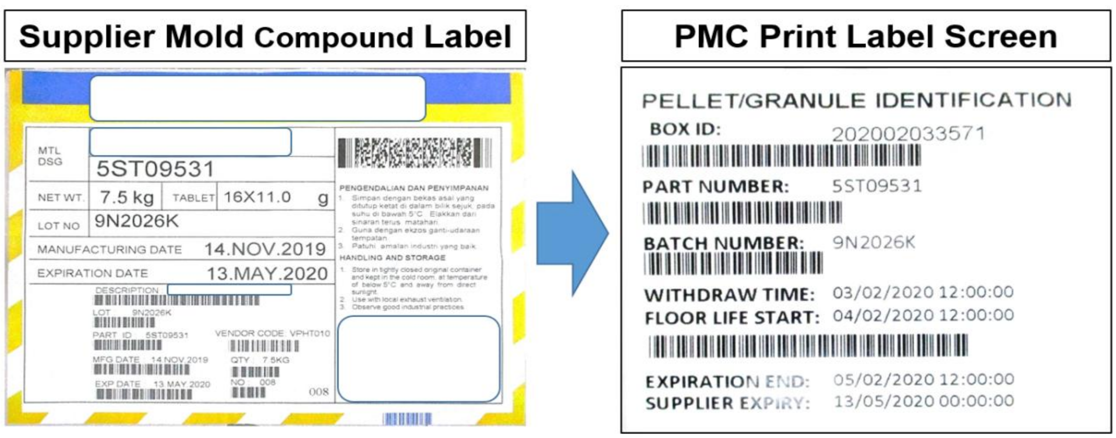
3.1 Test for Perishable Material Control Data Accuracy

Comparison of between actual EMC supplier label to the print out using perishable material control barcode label are all the same on all data entry. Actual images of both labels as shown in Fig. 17.

Using 2 proportion test, accuracy of pellet/granule label was compared between manual fill-up and PMC. At 95% confidence level, with a Pvalue of 0.0434 there is significant difference between manual and PMC. There is no discrepancy recorded using PMC. Details as shown in Fig. 18.

3.2 Test for Auto-lock Cabinet System Functionality

Using 2 proportion test, accuracy of thawing status and label was compared between open rack and auto lock cabinet system. At 95%



(a) (b)

Fig. 17. (a) Actual supplier mold compound label, (b) actual PMC print label using the same mold compound label

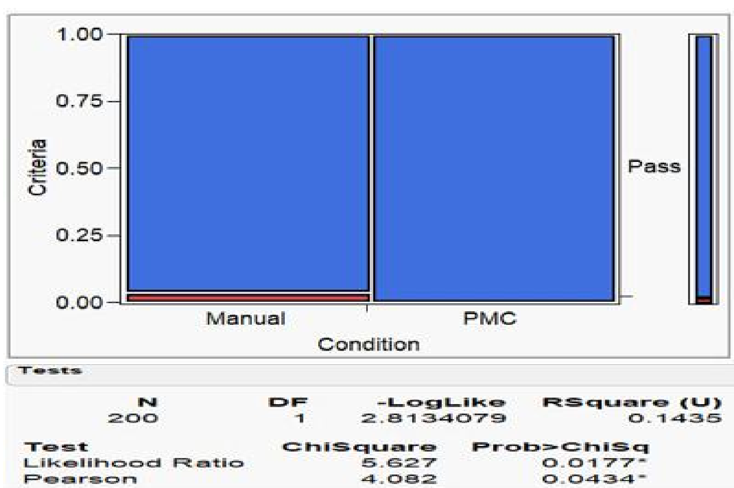


Fig. 18. Two proportion test between manual and PMC label accuracy

confidence level, with a Pvalue of 0.0235 there is significant difference between open rack and auto lock cabinet system. There is no discrepancy recorded using auto lock cabinet system. Details as shown in Fig. 19.

3.3 Test for FW2 System Upgrade for Mold Compound

FW2 system upgrade was able to provide a pre-alert time, offset time and expired alarm that lead to transaction disabled as shown in Fig. 20.

After implementation of all the automation solution starting Q2'19 there was no recorded cases of EMC misprocess up to date as shown in the Fig. 21. The project was able to eliminate occurrence of possible mold misprocessing related to EMC thawing thereby avoiding cost due to potential lots affected.

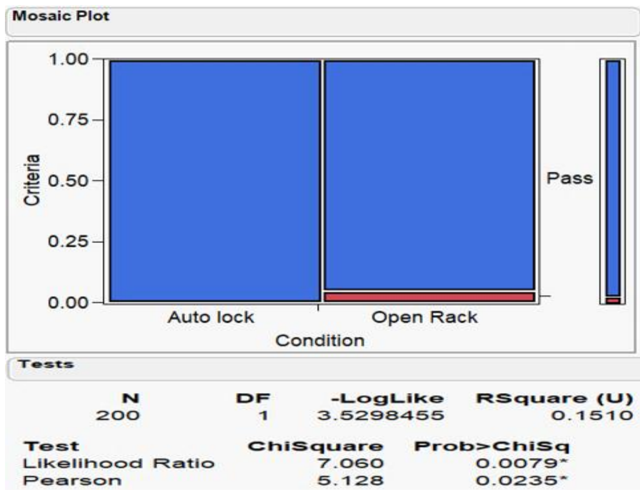


Fig. 19. Two proportion test between open rack and auto lock cabinet accuracy

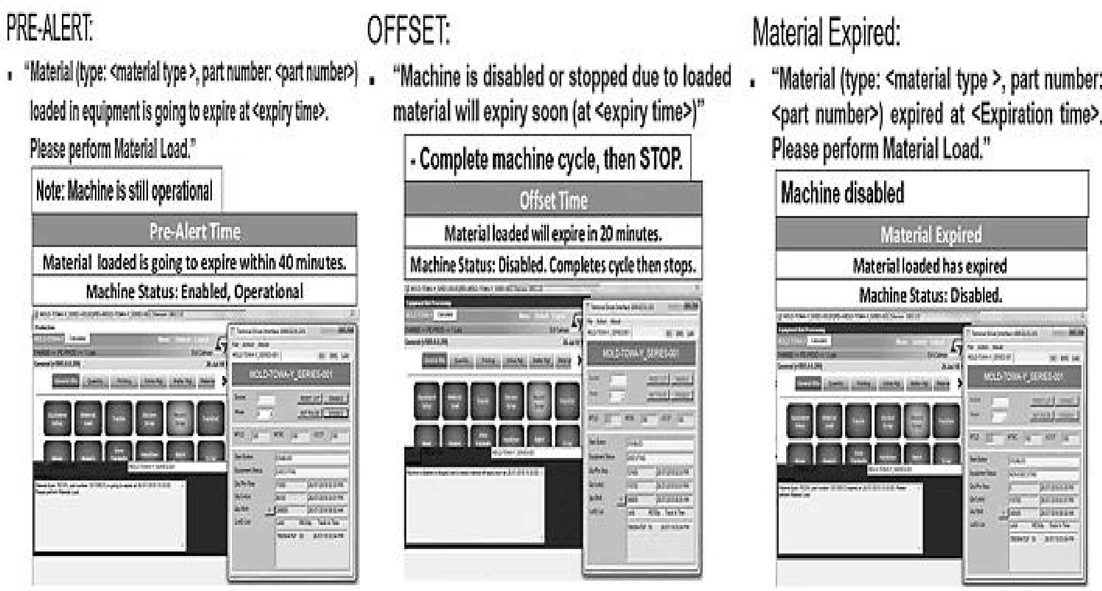


Fig. 20. Actual FW2 pre-alert display

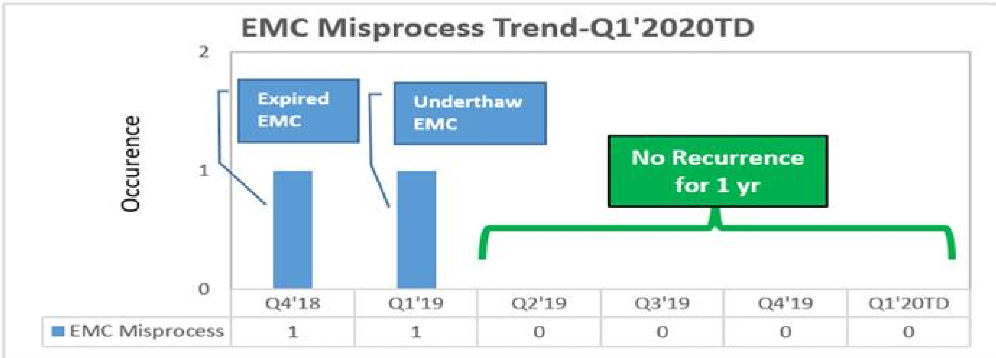


Fig. 21. EMC misprocess trend Q1'2020TD

4. RECOMMENDATION

It is recommended to fan-out as applicable all automations created for EMC handling from this paper to other direct and indirect materials. There is a need to further error proof EMC from misprocessing at machine level as FW2 upgrade only prohibits transaction of lot but physically machine will continue running using EMC. Applying same principle as PMC, mold equipment system can cross check if material and recipe are matched, detects expired EMC loaded from machine database and trigger automatic dumping. This concept is currently being discussed with mold equipment manufacturer. Share learnings and cross fertilized known best practice to other ST sites to further enhance if there are other unforeseen misprocessing weakness that was not addressed in this paper.

5. CONCLUSION

Perishable material control, PMC, system eliminates manual fill up of EMC traceability in thawing with high accuracy and with database useable for other system interface, FW2.

Mold compound control system and auto lock cabinet makes EMC and labels secured until it completes cycle of thawing with proper location and status traceability.

Lot management system, FW2 upgrade was able link the perishable material control system database to pre-alert, disable and shutdown machine through restriction in lot transaction once wrong mold, under thaw or expired EMC was detected.

These compound handling automations eliminated mold compound misprocessing which resulted to a cost avoidance from potential lot scrappage.

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.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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