The Wafer Breakages Reduction Using Kaizen Approach

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Abstract

The solar industries not only suffers from shortage of silicon but also price hike as a consequence in other hand the competition are high they need to reduce the selling price in order to be competitive. With current cost of silicon wafer that representing 60% of the solar cell cost rather than getting cheaper solar cell from the manufacturer, there is a new growing trend to reduce the silicon wafer thickness from 200micron to 180 micron and future to 150 micron later and leading to new technical challenges related to manufacturing process. Specifically on wafer breakage during handling and transfer is seem to be a huge significant issue. Therefore improved methods for breakage free handling and transferring methods are needed to address. The lacking knowledge of wafer handling devices at final electrical characteristic including the pick and place, flipper over unit and rotation table which is an air flow and vacuum tip nozzle device. Final result of the project, the initial breakage rate was 0.063% reduced to 0.008%. We believe with the implementation of in line filter element and continuous improvement at tester area will contribute to zero breakage in near future. Improve method are created to future reduce and improve others failure of above mentioned mechanical and pneumatic system with kaizen approach in Semi Medium Enterprise.

Keywords
Kaizen approach, Wafer breakages, Semi Medium Enterprise

1. Introduction
1.1 Introduction to solar manufacturing process
A solar cell is an electrical component that converts part of the radiant energy contained in light into electrical energy. Cells are the initial product in the manufacturing process of silicon based solar cells involving several stages. It is a simple solar cell structure based on two differently doped layers. In analogy to transistors in the electronics industry they are called emitter (n-type doping) and base (p-type doping). Using this so-called p-n junction, the charge carriers produced by the photo effect are separated and extracted for external use as electricity via metallic contacts. Cells or also known as wafers are cut from high purity crystalline silicon blocks with wire saws in wafer plants. The surface damage caused by the sawing process is removed by wet chemical etching treatment in the first cell manufacturing process step. It is also possible to texture the wafers surface in this etching treatment step, which increases the absorption of sunlight. After the etching, the wafers are cleaned using a wet chemical process and then dried. The next step in the process is phosphor diffusion. The wafers are exposed to a phosphorous gas in a diffusion furnace at around 900 °C and oxygen is introduced causing a phosphorous oxide to form on the surface. Phosphor atoms then diffuse into the silicon and the n-type emitter is created. The penetration depth is determined by various factors, in particular temperature and the duration of diffusion. In the next stage of the process, the phosphorus glass produced on the surface is removed using a wet chemical treatment. An anti-reflection coating is applied to the front side of the wafer to increase the solar cells absorption of sunlight and to improve the electrical properties of the surface and base material. The most effective method for applying the anti-reflection coating made from silicon nitride is plasma enhanced chemical vapor deposition in a "PECVD" system. Using a silk screen printing process, narrow contact fingers containing silver are printed on the front side, as well as two to three wider strips perpendicular to the contact fingers the so-called bus bars. On the back side bus bars are applied using a silver/aluminum paste. The remaining back surface is imprinted with aluminum in a further printing stage. A drying process in a special furnace takes place after each printing step. When all printed contact materials are dried, they are thermally fired to ensure good electrical contact with the silicon. A solar module is a photovoltaic component designed for direct use by end customers and which has the electrical contacts required for connection to

an entire solar system. In solar modules based on crystalline solar cells, the individual solar cells are electrically connected in series using contact ribbons. The matrix of solar cells is laminated between a glass panel and several foils of plastic materials at sub-atmospheric pressure and at an elevated temperature to make it weather-resistant. The solar modules are then fitted with a frame and a junction box, and are then ready for installation on rooftops or in solar power stations.

1.2 Problem statement

To date solar cell technology offers a leading edge level of efficiency in mass production. Thanks to it highly efficient processes, As we know that silicon is initially crystallized to ingots a silicon blocks or columns of silicon which are later cut into wafers using a wire saw with suspension and then cleaned. Practically the cell thickness are in range of 180~200 micron. Manufacturer had produce thinner wafer due to hike on silicone price. But the major drawback when the thickness reduces it contributes to high breakages. A broken wafer is a loss and an opportunity. When a wafer breaks figure 1 and figure 2 during processing the first impulse is to clean up the mess and trash the broken pieces and not to forget the hazarded of it share edges. Broken wafer can be sold in much lower price to industries that applied solar power device on this product such watch and calculator manufacturer. Any how it does not compensate the initial buying price. But today with high competition from other major player the product price are reduce but the base material price are increasing due to demand not only from solar industries bur also electronic industries that used it as based for integrated circuit.

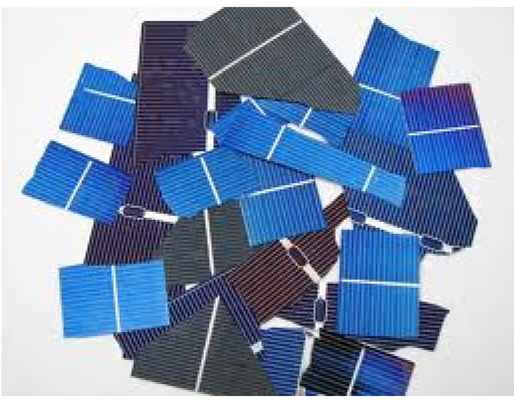


Figure 1: Large breakages

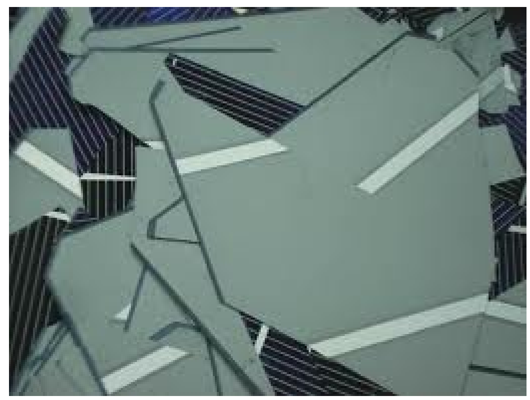


Figure 2: Small Breakages

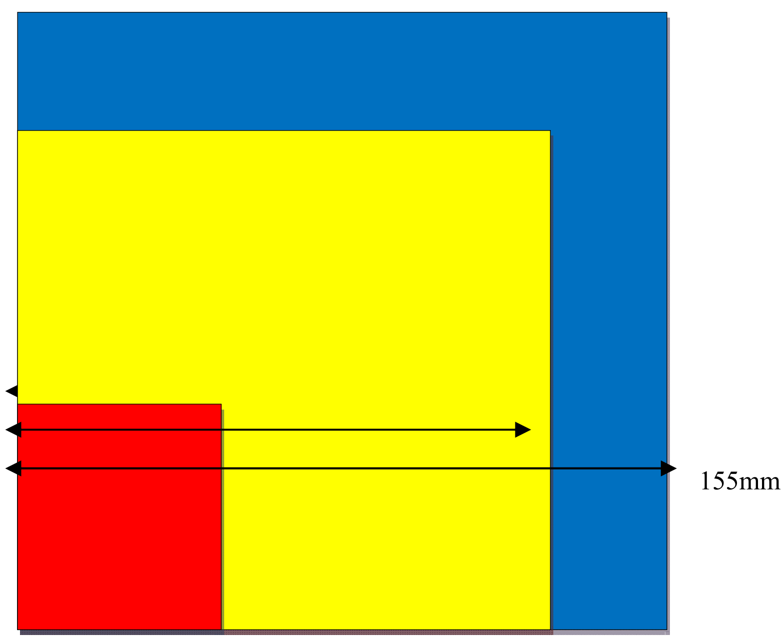
They are many reasons that causing the breakage such us incoming material itself, handling issue, tools malfunction and others related factors. When we observe the fracture markings on the broken edges actually represent a detailed recording of the rapid sequence of events that took place during the breakage event. By examining the fracture markings with a microscope, it is often possible to discover how and why the wafer broke so that appropriate corrective and preventive actions can be taken. A wafer begins to break apart when the silicon at some surface location is subjected to a sufficiently large tensile stress. The tensile stress can arise due to wafer bending, uneven cooling, penetration, or during an impact when the silicon is compressed in one direction but pulled apart in other directions. The stress required to break a wafer is greatly reduced if the wafer surface has a stress concentrator such as a preexisting crack. We need to analysis and discover how and why a wafer broke so that future occurrence can be prevented. If a wafer broke because of a weakness such as a scratch that occurred at a prior processing step then that weakness can be eliminated. If a wafer broke because it was bent or penetrated by a piece of wafer handling equipment, then that equipment can be adjusted. A broken wafer is not only a loss but an opportunity for improvement. That is the reason why this project are been selected. After collecting the required data a rough guide had been implemented in order to reduce breakages level before any improvement activities taken, as per following table. This would help personnel from maintenance, quality and operation to adhere to standard of performing task to reduce the number of breakages.

2. Literature Review

The wafers are one of the main assets in solar cells production. Crystalline silicon (Si) has taken a dominant role in contributing to over 90% of the entire solar power module production. It is important to recognize that the silicon wafer is a large contributor, up to 75%, to the overall cost of the solar cell. The wafers will gradually be thinner to reduce material costs. To contribute in cost reduction and compensate for the feedstock shortage, solar wafers are sliced thinner with thicknesses down to 150 microns due to this the as such company rules stated that every employee is required to handle the wafers with care and avoid the breakage of cells and wafers. In even of breakages we need classify it accordingly this because of wafer recycling activity. In order to help operator segregated the breakages accordingly below method used, by using the breakage wafer/cell reference format, we can define the size of breakage wafer or breakage cell. Although the concept of applying fracture physics, through single particle breakage, to comminution processes was pioneered by Rumpf beginning in the 1960's, the first single particle tests where conducted in the 1930's (Carey and Bosanquet, 1933). The purpose of these tests was to determine the energy necessary to reduce coal and gypsum particles (ranging from 2 to 50 mm) to a certain size The breakage wafer or breakage cell is measured by referring it physically to the reference format. For example, if the breakage wafer can fully cover the 125mm x 125 mm box, it will be defined as large breakage.

Table 1: Possible Prevention Area

Related Process	Description
Loading and unloading	• Avoid unnecessary loading and unloading of wafer carriers. If required, request additional carriers for temporary • If cells are loaded or unloaded by hand to/from carriers, this shall be executed only outside of the system. • If cells/wafers are unloaded, the Styrofoam boxes must be used as buffers. The maximum capacity is100 cells. • No pile up carriers loaded with cells/wafers. Used the fixture during loading/unloading. The carriers must place on proper place such as rack and trolley
Transportation	• Place and transport loaded carriers and Styrofoam boxes only on pneumatic carriages with rubber mats • Do not pile up carriers loaded with cells/wafers. • Carry the magazines/carriers in proper ways
Automation	• The automation must be permanently monitored, to detect breakage and deviations as quickly as possible. Each deviation must be remedied immediately. • If heavy breakage occurs, stop the system and inform respective team.



Above criteria are purely for those handling breakage during data collection. During real-time production, we need a feedback system from the tool user to the tool owner in event of breakage is out of tolerance. The breakage triggering rate/limit had been created it is six pieces at tester area per hours and this is limits to stop and rectify the tools by the respective owner. If the breakage rate hits the triggering limit by hour, dedicated action plan should created and implement in order to contain the breakage rate from going higher. During the project we managed to build a breakages data catalogue this for faster breakage root cause finding and recognition in respective process areas. The dimensions of defect are in all shape and sizes.

2.1 Breakages Catalogue

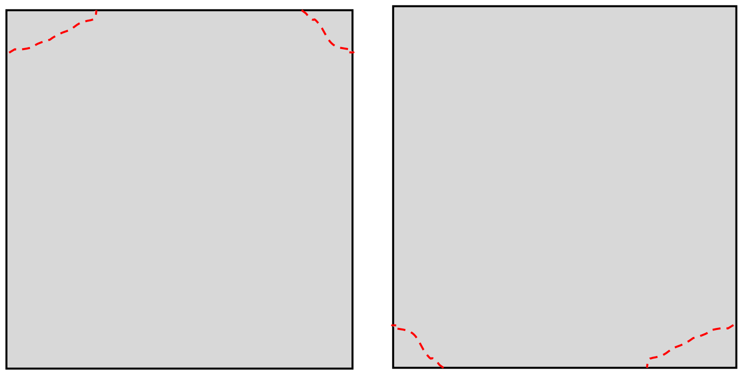


Figure 4: Loading area

Loading area – where throughput loss because of improper handling during loading. Ensure that unpacking is done at clean no splinters and other contaminants and padded work station with special underlay cardboard. With possible breakages at every edge as prefigure above.

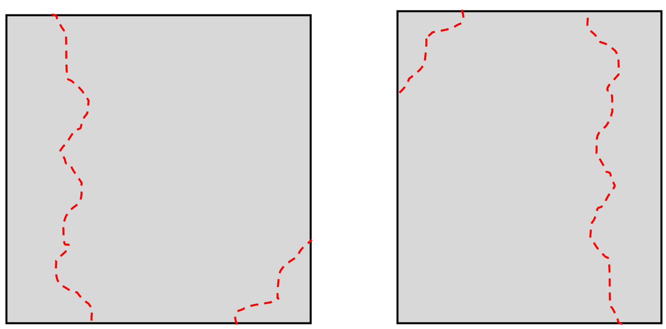


Figure 5: belt magazine the abrasion caused by the belt magazine at the wafer loader

Since wafer been transport through carrier called belt magazine the abrasion caused by the belt magazine at the wafer loader will cause following breakages as per fig 5. Operator need to check the belt magazine rollers and air nozzles for any abnormality. This also possible to occur when splinters trapped on the conveyor rollers of the tester and the concentricity of the rollers is out. Operator must removes the splinters trapped on the rollers and ensure that the concentricity of the rollers is not out.

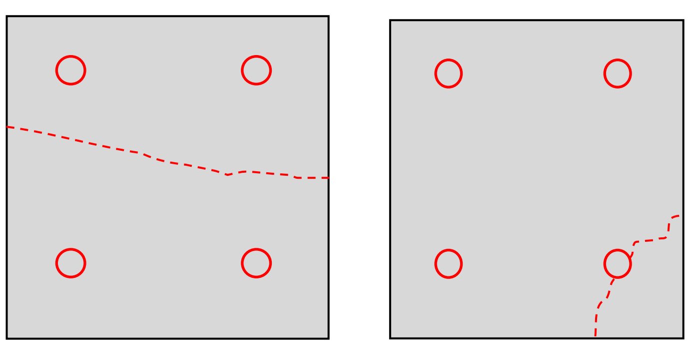


Figure 6: splinters in the suction cups of the wafer picker

Following is wafer breakage fig: 6 due to splinters in the suction cups of the wafer picker. Operator need to removes the splinters from the wafer picker. Other possible is wafer hitting carrier guide bars. Maintenance personnel need to recalibrate or correct the wafer position when entering the carrier. Wafer must not touch or hit the guide bars. With this breakages catalogue we also manage to map out all the cell contact point with the tools moving part as depict below

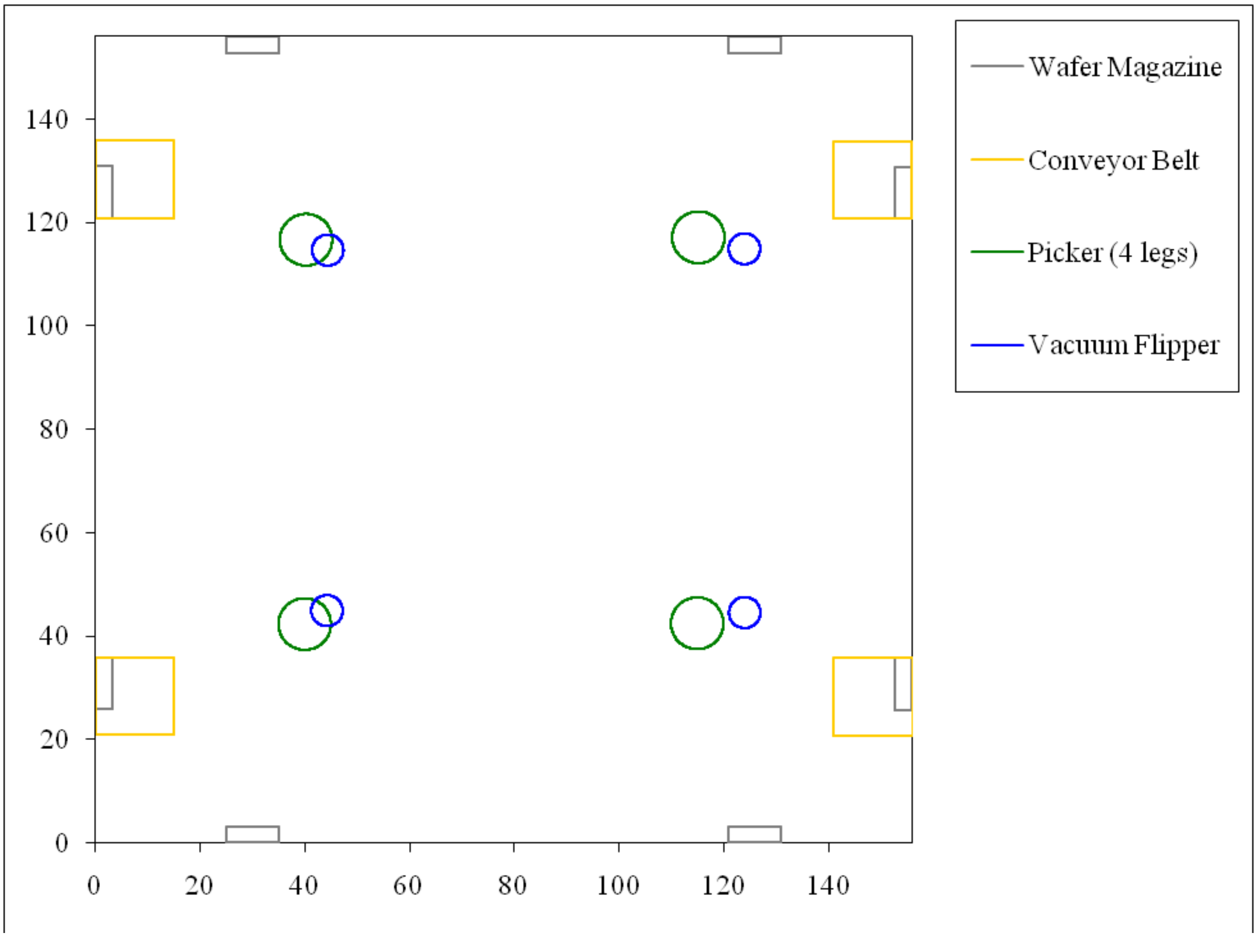


Figure 7: Cell contact point mapping/ template

3. Research Methodology

3.1 Data Collection

Regardless of the field of study or preference for defining data accurate data collection is essential to maintaining the integrity of project. Both the selection of appropriate data collection instruments and clearly delineated instructions for their correct use reduce the likelihood of errors occurring. The first step is gathered the data at the entire tester in event of breakages operator will update record in sheet with references of the location of the incident. These check sheets are actually tester layout diagrams, which show where a particular problem occurs. The spatial location is valuable in identifying root causes and planning corrective action. The diagram makes it easy to identify a problem area that would be difficult to depict otherwise. In this case, a picture is truly worth a thousand words of explanation. The data had been complied for duration of 6 month. The process of gathering and measuring information on variables of interest in an established systematic fashion that enables one to answer questions which tools that contributes to highest breakage. The result had projected as per below table:-

Table 2: Data collected from the entire tester for duration of 6 Months

Tools	A	B	C	D	E	F	G	H
Σ Incoming	1868507	1500326	1870460	1611604	2485427	1448778	2288023	1420612
Σ Breakage	438	608	609	526	641	226	620	292
Percentages	0.023%	0.040%	0.033%	0.033%	0.026%	0.016%	0.027%	0.02%
Tools	I	J	K	L	M	N	O	P
Σ Incoming	2190948	2075374	2186208	2039093	978911	0	1460499	0
Σ Breakage	1067	1295	771	1190	571	0	893	0
Percentages	0.048%	0.063%	0.035%	0.058%	0.058%	0	0.061%	0

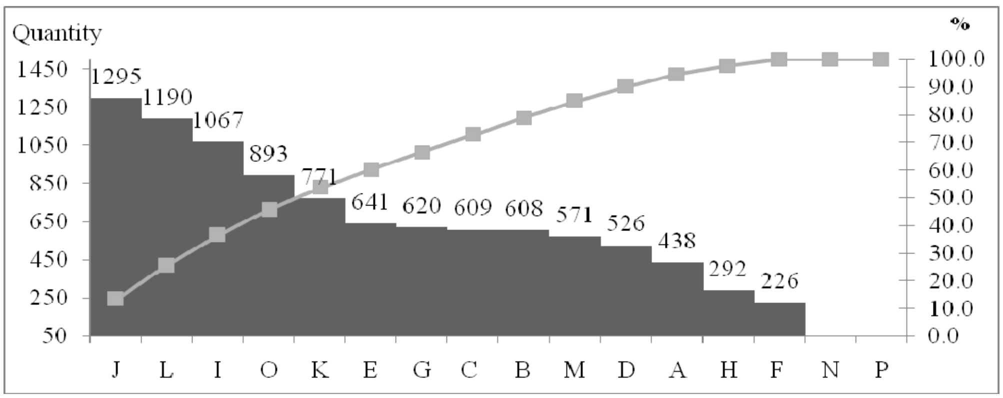


Chart 1: Pareto of Breakage Quantity by tester from June to December 2011

From the data comparison we can conclude that tester I, J and L are the top three but we should choose tester J due to the highest breakage quantity. In relation to the percentage the result is different H, F and A is the highest. Since we choose the tools based on high number of breakages not the percentages this is mistake during tools selection had been advice by the project supervisor. This will be the guide line for us how effective all the action that will implement to reduce the percentage. By successfully implementing the desirable project at the problematic tools it would guide us on further improve other stabilize tools. We unable to eliminate the breakage to zero because there is other minor factor that not been identify or missed out during the data collection or during improvement project implementation.

3.2: Target breakage reduction for Tester J

We must consider that the important of every data integrity and eliminated of errors in the data collection process, whether they are made intentionally or not. Most, Craddick, Crawford, Redican, Rhodes, Rukenbrod, and Laws (2003) describe ‘quality assurance’ and ‘quality control’ as two approaches that can preserve data integrity and ensure the scientific validity of study results. Based on this, we can draw out the losses per month. Further nine more week data gathering had been carrying out after identify the best selected tools that is tester J, this is in order to set the targeted and achievable ratio of breakages reduction. We conclude that after considering the lowest and highest ratio from the table 4, we are able to reduce 69%.

Table 3: 9 week data collection

WW	WW1	WW2	WW3	WW4	WW5	WW6	WW7	WW8	WW9
No of breakage	86	52	85	162	138	126	75	127	168

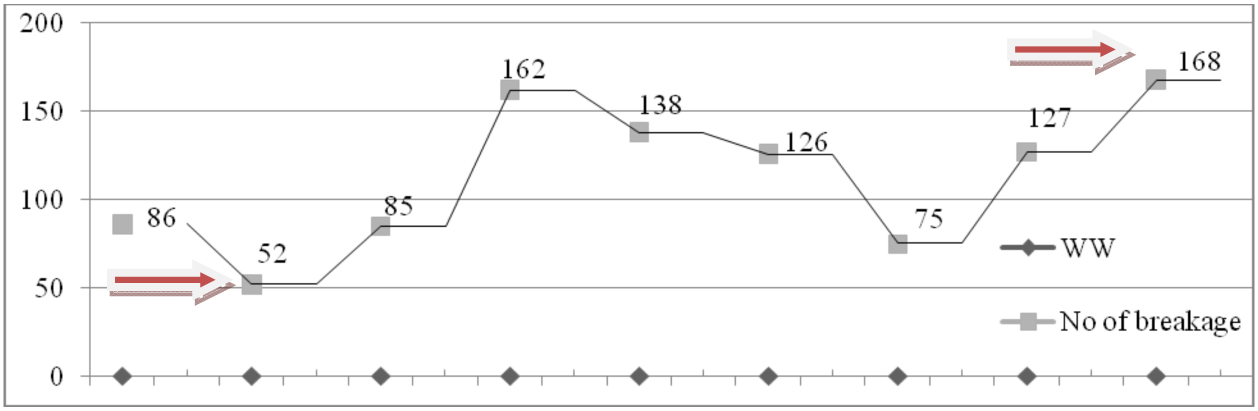


Chart 2: Number of breakages for 9 weeks

Table 4: Targeted achievable reduction ratio

Sources	Tool	Data period		No of days	No of breakages	Breakages / day	Corrective action / breakages (Seconds)	Time loss / day (minutes)
		From	To					
Data	Test-J	Dec 2011	Jan 2012	63	1019	(16.17) 17 days	60	17

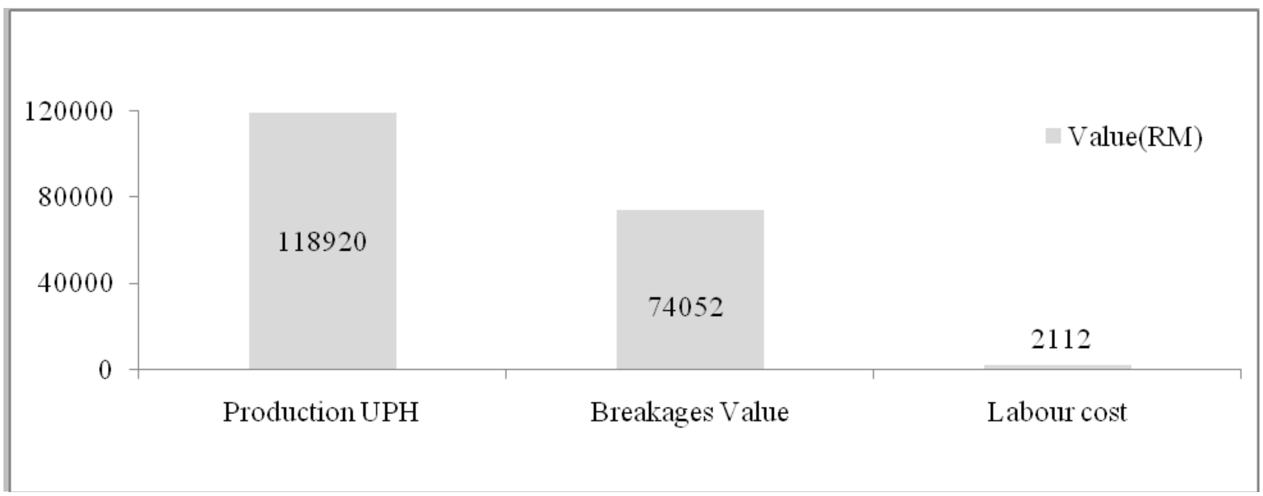


Chart 3: Distribution of loss and cost per year

3.4 Improvement Area

From the data and mapping (appendix 1 & 2) we conclude that area needs to focus and improve are as per following:-

- The pick and place (PNP) that pick-up the wafer cells in slanted position will affect for early stage of breakage, contribute to 45% of breakage. Ejector spring in the housing stuck & created the impact force during pick up wafer
- The acceleration of potential energy by drop height will lead to micro crack at flipper section lead to 25% breakage.
- Wafer release (drop) & misplaced (skew) during rotary movement due to insufficient vacuum (or not all vacuum nozzle is function) contribute 25%
- The failure of electro-pneumatic parts will lead to insufficient vacuum level with wrong timing and vacuum lost will cause breakage is 5%.

As improvement step had been plan ahead we need to take few precautions methods in order to help minimize the current breakages rate before the, says activity been carry out and result been obtain. Following control parameters give the clear indication area need to be focus it consists of lists of items and some indicator of how often each item on the list occurs. This simplest form of checklists are tools that make the data collection process easier by providing pre written descriptions of events likely to occur.

Table 5: Control parameter that had been implemented

Cell Tester Process Description	Equipment, Jig & Tool	Characteristic	Process Specification	Measurement Techniques	Sample		Reaction Plan	Process Owner
					Size	Frequency		
Loader	Wafer separation	Ensure among 4 pickers are parallel no stuck	Picker is not stuck cause wafer bowing	Manual push on picker for verification	3 times	Beginning of the shift	Picker cleaning & replace	
Loader & Sorter	Picker (PNP)	Ensure vacuum cup is not wear and tear	Vacuum cup is not wear & tear.	Visual	1time	PM	Replaced new vacuum cup	MNT
Flipper	Flipper	Ensure there is no broken piece, wafer expose on conveyor	No broken piece wafer expose on conveyor	Visual	3 times	Beginning of the shift	Perform cleaning	OPR
Sorting bin	Sorting bin	Ensure there is no broken piece, splinter inside sorting bin	No broken piece wafer expose on sorting bin	Visual	3 times	Every shift	Perform cleaning	OPR

Following are the identify area need to be improve and below figure is the part need to modify, enhance and fabricated that correlated to above mentioned improvement step and action:-

- Fail safe clamping mechanism to ensure the 4 PNP pick up moving together

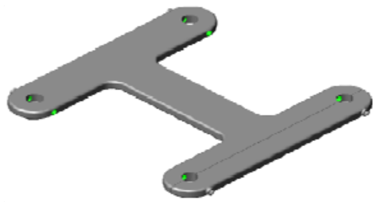


Figure 8: Leveling Clamper

- To protect & increase the lifespan of the electro-pneumatic parts and to maintain the efficiency of signal transfer that control the movement

Figure 9: inline filter

- To reduce the flip over's drop height to prevent micro crack to wafer

Figure 10: Nozzle spacer

- To maintain the functionality of Ø 5mm spring as an impact absorber for PNP picker

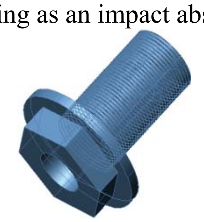


Figure 11: M10 housing base

The investment involve during that implementation is as per table 4 below:

Table 6: Total investment

No	Item	No of parts / module	No of Tools	Price / Part	Total (RM)
1	Leveling clamper	1	1	65.00	65.00
2	In-line filter	2		168.50	337.00
3	Nozzle spacer	8		10.00	80.00
4	M10 housing base	4		50.00	200.00
				One time investment	782.00
1	Drill bit holder	1	1	57.00	57.00
2	HSS Ø1mm drill bit	1		3.00	3.00
				Consumable investment	60.00
				Total Investment	842.00

4. Results and Conclusion

4.1 Results

The overall result show significant improvement during second wave of data collection as depict below table. During first week of implementation breakages rate is 26pcs. After investigate we had been inform there is new batch of operator been assign at this particular tools. The total number of breakages was mixed up with break due to handling error also been included. Second is the number of volume that supply had reduced from week 16 onward due to the company financial situation and most of the activity had been review on weekly basis. At certain point of time the tester had been idling without any material been load or feed into the system. Even the implementation of in line filter is on hold at the moment. If the incoming volume is homogenous we expected to depict the overall result showing reflect a huge improvement. Another influence factor that we notice is the variations of supplier. On week 16 itself there is change of material supplier this cause of slightly high percentage.

Table 7: Breakage after implementation

WW	WW13	WW14	WW15	WW16	WW17	WW18	WW19	WW20
Σ Incoming	290149	289289	250155	188190	148035	106785	48554	58039
Σ Breakage	26	12	13	17	13	11	8	7
Percentages	0.009%	0.004%	0.005%	0.009%	0.008%	0.010%	0.016%	0.012%

End result of the project can view by below table, 8 the initial breakage rate was 0.063% reduce to 0.008%. We believe with the implementation of in line filter element and continuous improvement at tester area will contribute to zero breakage in near future. Another positive point that we notice that the project does not required any FMEA as the project only apply with methods of retro-fit type improvement that is very flexible less tear and wear second there is no direct contact to wafer and lastly no changes in tool parameter, require no calibration or process change.

Table 8: Breakage rate comparison at tester J before and after

Overall Result	Before	After
Σ Incoming	2075374	1379196
Σ Breakage	1295	106
Percentages	0.063%	0.008%

4.2 Conclusion

With a successful outcome of breakage reduction this leads to waste elimination, reduction in operating costs, improved quality in product outputs, and higher customer satisfaction. Productivity and profitability increase when these strategies are applied in tandem by the management for optimizing their potential and reaping full benefits. The successfulness of this project is large depend on the support of the management team without their concern and motivation it is possible to achieve the desirable goals. During implementation we had the opportunities to further improve the plan design and reduce the overall cost modification for example on the leveling clamper unit that had been eliminated due redesign of picker shaft. We hope with improvement it further bring down the company operation cost and make more competitive in the market. Further study on the mechanical stress on wafer should be carryout to eliminate per mature breakage or micro crack on the wafer. We understand that micro cracks will increase the breakage risk over the whole value chain from the wafer to the finished module because the wafer or cell is exposed to stress during handling and processing. The actual need to use larger and thinner crystalline silicon wafers due high cost increases the risk of yield losses. Besides the breakage risk in the production, the cells have to withstand the tensile stresses under outdoor operation in the finished modules.

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Biography

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