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Quality Improvement Using The DMAIC Method To Reduce Defect Product In The PVC Compounds Industry

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Abstract

Background: PVC Compound Industry is an industry that is engaged in the production of PVC Compound which is specially designed to meet the needs of the plastic industry market. The number of defective products produced by this industry is very large, so the quality of the company's products is low. The high number of defective products resulted in losses to the company. This study aims to reduce the rejection rate on PVC Compound. This research is a case study in the PVC Compound Industry.

Methods: This study uses the DMAIC method. This research is included in the mixed-method research. The data used include primary data and secondary data. This study uses Focus Group Discussion to analyze problems and provide suggestions for improvement.

Result: Based on data analysis, the three biggest defects are Surfacer, Dispert and Unmelt. Surfacer defect improvement is done by increasing the temperature and lowering the RPM. Improvements to the Dispert defect are by adding blending time and checking the blender temperature and steam pressure periodically. While the improvement on Unmelt is by lowering the screw extruder temperature, lowering the screw extruder RPM and lowering the RPM. The results showed that the DPMO value decreased from 909 to 252 and increased the average sigma level from 4.62 to 4.98.

Conclusion: This study concludes that with the DMAIC method the company can reduce the rejection rate and increase the sigma level.

Keywords: DMAIC, Quality Improvement, PVC Compound, Six Sigma

1. Introduction

In this era of globalization, the growth of the manufacturing industry has increased rapidly. This development will create competition in the global market (Hernadewita, Rochmad, et al., 2019). Companies must have the right strategy to be able to compete in the global market (Desai & Prajapati, 2017). Every company must always make continuous improvements to compete with competitors (Rochman & Agustin, 2017)(Bhargava & Gaur, 2021). Customer satisfaction has a significant role to win the competition. In the manufacturing industry, customer satisfaction can be measured by the quality of the products produced (Pereiraa et al., 2019)(Prashar, 2017). Quality is very important. Companies that produce goods must be required to create quality goods (Ferrer-rullan et al., 2020). Achieving good quality is one of the strategies to win the competition (Abhilash & Thakkar, 2019)(Garg et al., 2020).

The PVC Compound Industry is an industry engaged in the production of PVC Compound which is specifically designed to meet the needs of industrial markets such as the automotive industry, household electronic toys and high-quality disposable medical devices. The company has large customers both at home and abroad. Plastic is a product that is widely used, both as finished products and as raw materials for other industries, such as the food and beverage, electronics, pharmaceutical, automotive, and construction industries. In the production process, there are always products that do not meet specifications or defects. Defective products certainly cannot meet customer satisfaction. This defective product will become an unused item and will make a loss to the company. Losses due to defective products include wastage of material, time, energy and storage costs. The high number of defective products produced resulted in high losses experienced by the company, both the cost of processing for reprocessing and losses due to wasted products. In addition, defective products have a major influence on the quality of the final product which results in a decrease in the efficiency and productivity of the company (Mathew et al., 2017)(Uluskan & Pinar Oda, 2019)(Hernadewita, Ismail, et al., 2019). This can lead to a decrease in customer satisfaction and company competitiveness (Sreedharan & Raju, 2016)(Pugna et al., 2016)(Hadidi et al., 2017).

Based on the phenomenon of the problem, a strategy and improvement are needed to overcome it. Six sigma is a method for reducing product variance (Yadav & Sukhwani, 2016)(Belu et al., 2018)(Sukwadi et al., 2021). This method is a manufacturing business process strategy that can be used by various companies to increase customer satisfaction (Syafwiratama et al., 2017)(Sachin & Dileeplal, 2017)(Rimawan et al., 2018). This method can also identify complex problems (Ishak et al., 2020)(Soundararajan & Reddy, 2020). In general, the implementation of six sigma is carried out in the DMAIC stage (Zaman & Zerin, 2017)(Bharara et al., 2018)(Setiawan & Setiawan, 2020). This methodology is a structured problem-solving step starting from determining the problem, measuring, identifying the cause of the problem, finding a plan for improvement and standardizing the results of the improvement (Costa et al., 2020)(Putri & Primananda, 2021). This methodology can provide effective results for optimizing product quality to obtain efficient production costs (Saxena & Srinivas, 2019). This study aims to reduce the rejection rate of PVC Compound in the PVC Compound Industry. This study uses the DMAIC method, namely Define, Measure, Analysis, Improve and Control.

2. Methodology

2.1. DMAIC framework

This research uses systematic and structured stages to get complex results. The DMAIC stages used are Define, Measure, Analysis, Improve and Control. The DMAIC framework in this study can be seen in Figure 1.

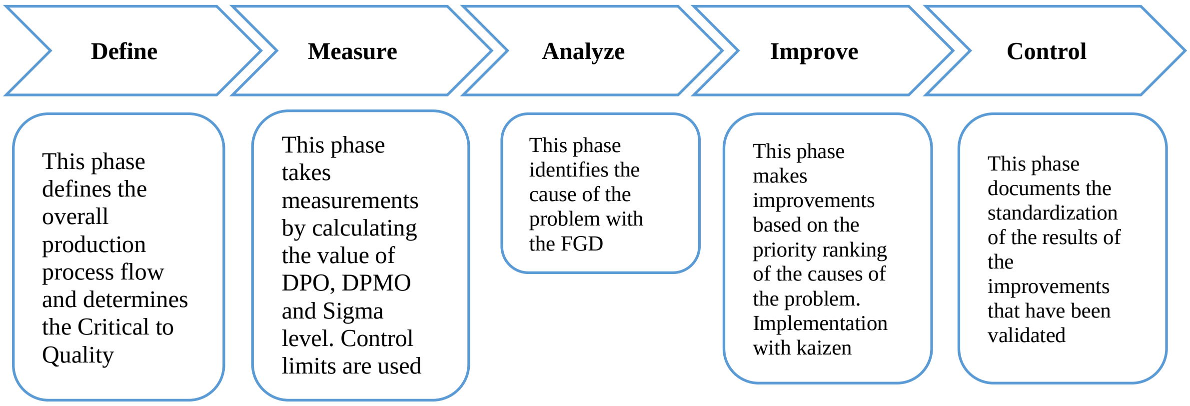


Figure 1. DMAIC Framework (Sharma et al., 2019)

2.1.1 Define

Define is the initial stage to determine the problem in research. In this phase, the production process flow mapping is carried out using the SIPOC diagram, then determines the Critical to Quality.

2.1.2. Measure

This stage is built to calculate the value of DPO, DPMO and sigma level. The quality control tool used is the P control chart to see the stability of the process. Here is the formula for the calculation at the Measure stage.

$$CL/\bar{p} = \frac{\text{Total defect product}}{\text{Total product}} \quad (1)$$

$$UCL = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \quad (2)$$

$$LCL = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \quad (3)$$

$$DPO = \frac{\text{Total Unit of Defect}}{\text{Total Unit x CTQ Opportunity}} \quad (4)$$

$$DPMO = DPO \times 1.000.000 \quad (5)$$

2.1.3. Analysis

In this phase, identification of the causes of problems that cause defective products is carried out. Identification is done by Focus Group Discussion (FGD) with the parties involved, namely expert judgment. The tool used is a Fishbone diagram. FMEA is used to determine the priority ranking of problems that will be repaired through the calculation of the Risk Priority Number (RPN), following the formula:

$$RPN = S \times O \times D \quad (6)$$

Each Severity (S), Occurence (O) and Detection (D) mode is based on a scale of 1 to 10. In Severity, 1 indicates Rarely and 10 represents Frequent. In the Occurence level, 1 indicates Insignificant, and 10 indicates Dangerous. Lastly, in detection, 1 refers to Easily Detectable and 10 describes Detection Highly Impossible

2.1.4 Improve

The improve phase is built to make improvements based on the highest ranking on the RPN value. The analysis was carried out using the 5W1H method. Then implement improvements with Kaizen

2.1.5 Control

The Control phase is used to control the improvements that have been made and validation tests. Implementation of this phase by monitoring all production results and documenting the process until making Standard Operation Procedures (SOP)

2.2 Data Collection

This research is a mixed-method, which is a combination of quantitative and qualitative research. This study uses primary data and secondary data. The primary data used were obtained through observation, field studies and FGDs. The primary data used are the flow of the production process, equipment and machinery and the number of operators. While the secondary data used is obtained from the company's annual report such as data on production capacity and the number of defective products.

3. Result and Discussion

In this chapter, improvement analysis is carried out according to the methodology used, namely DMAIC. The research implications are also discussed at the end to find out the contribution of this research to similar industries.

3.1. Analysis DMAIC

3.1.1. Define

The first step in the define stage is to define the production process flow for making PVC compounds. Mapping the flow of the production process using the SIPOC diagram which can be seen in Figure 2.

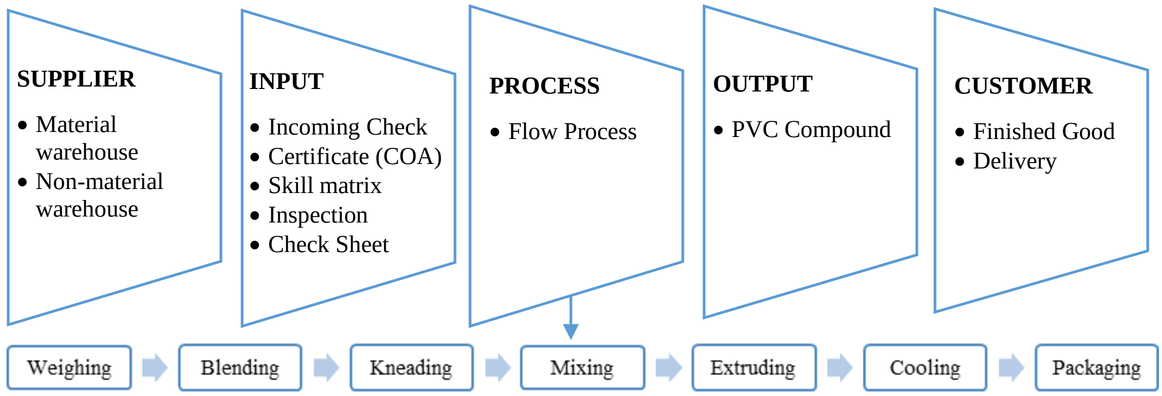


Figure 2. SIPOC Diagram of PVC Compound Production Process

Defects occur because the products produced do not meet the specifications set by the company. Defects that occur in the production process are high enough so that customer satisfaction is reduced, it is necessary to make improvements. Based on the Pareto diagram in Figure 3, the biggest defects that occur in the production line occur in Surface, Disperse and Unmelt with a calculation of 78.2%.

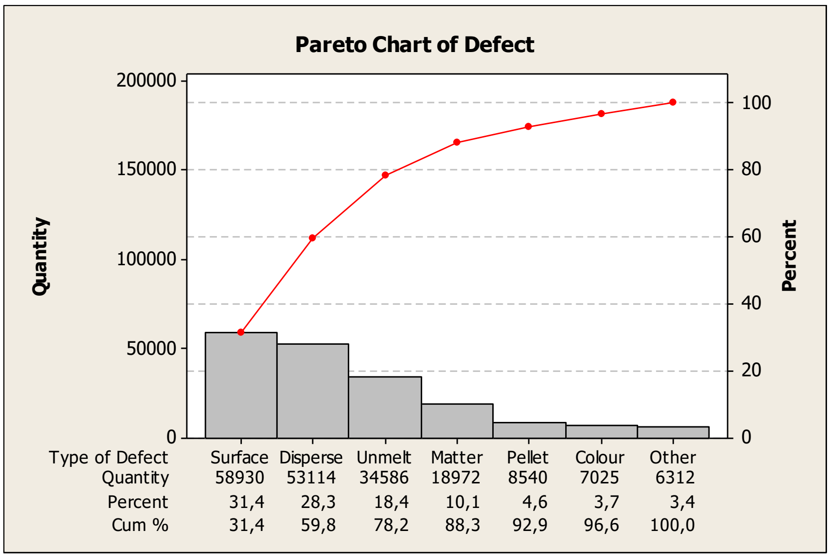
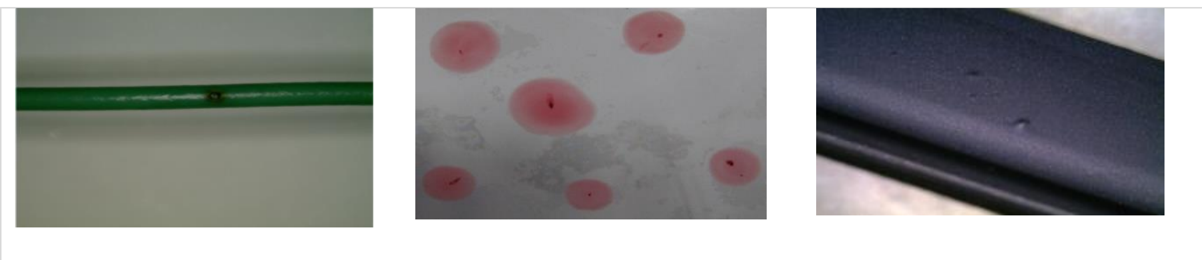


Figure 3. Pareto Diagram of Defect

Based on the Pareto Diagram, it can be determined the CTQ of the PVC Compound manufacturing process. As for the CTQ in the PVC Compound manufacturing process, there are 3 items, namely the resulting product must not be surface, disperse and unmelt. These CTQs are attributes that are highly standardized by companies and customers. The following defects are used as CTQ can be seen in Figure 4.



Surface	Disperse	Unmelt

Figure 4. Defect Product

3.1.2. Measure

Figure 5 presents the Control P diagram of the process using equations (1), (2), and (3). Even though all points are within the control limits, the center-line is still above the tolerance limit set by the company, which is 0.04%.

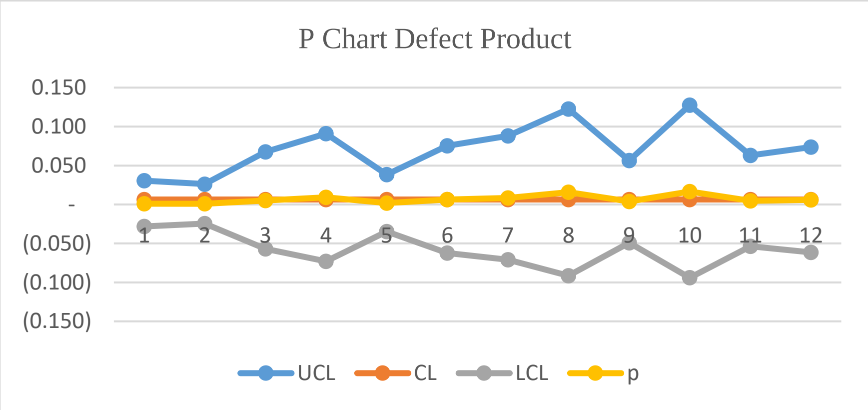


Figure 5. P Chart of Defect Product

After knowing the stability of the process on the Control Map then calculating the value of DPO, DPMO and sigma level. Calculations are carried out using equations (4) and (5). The calculation results can be seen in Table 1.

Table 1. Calculation results of DPMO and Sigma Level

Months	Total Production	Defect	CTQ	DPU	DPO	DPMO	Sigma Level
Jan	3,727,159	4,334	7	0.001	0.000166117	166	5.09
Feb	3,503,772	3,011	7	0.001	0.000122766	123	5.17
Mar	2,590,930	13,452	7	0.005	0.000741708	742	4.68
Apr	2,497,164	22,518	7	0.009	0.001288204	1,288	4.51
May	942,989	1,700	7	0.002	0.00025754	258	4.97
Jun	1,485,811	9,446	7	0.006	0.00090821	908	4.62
Jul	1,595,329	13,579	7	0.009	0.001215961	1,216	4.53
Aug	2,101,476	32,708	7	0.016	0.002223471	2,223	4.34

Sep	2,662,413	9,967	7	0.004	0.0005348	535	4.77
Oct	2,866,665	47,672	7	0.017	0.002375682	2,376	4.32
Nov	2,895,563	13,198	7	0.005	0.000651144	651	4.72
Dec	2,606,098	15,893	7	0.006	0.000871198	871	4.63
Total	29,475,369	187,478	7	0.006	0.000908642	909	4.62
Average	2,456,281	15,623	7	0.006	0.000908642	909	4.62

Based on Table 1, it can be seen that the average DPMO value in 2020 is 909, while the Sigma Level value is 4.62. This value is included in the very good category which is an industry category in America. However, this value has not met the target set by the company of 5.00.

3.1.3. Analyze

In this phase, the identification of the main causes of the three biggest defects is carried out. Analysis and identification of causes of defects based on FGDs. The tool used in this stage is the Fishbone diagram. The following is an analysis of the factors causing each defect using a fishbone diagram can be seen in Figure 6, Figure 7 and Figure 8.

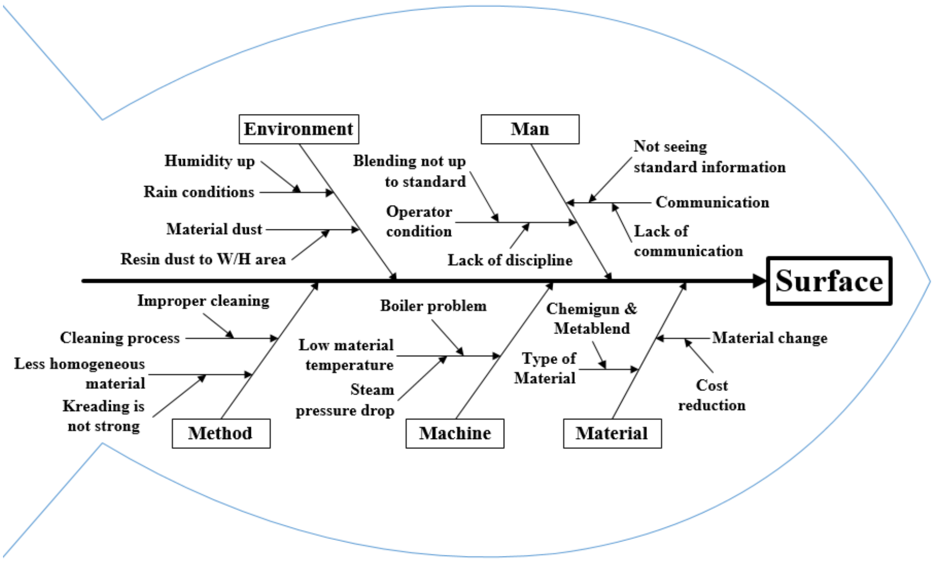


Figure 6. Fishbone Diagram of Surface

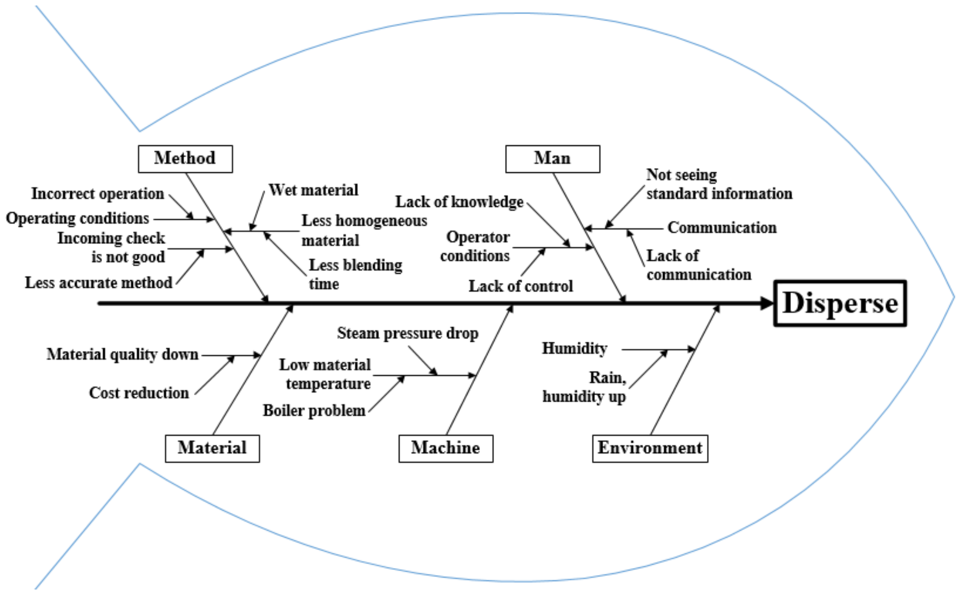


Figure 7. Fishbone Diagram of Disperse

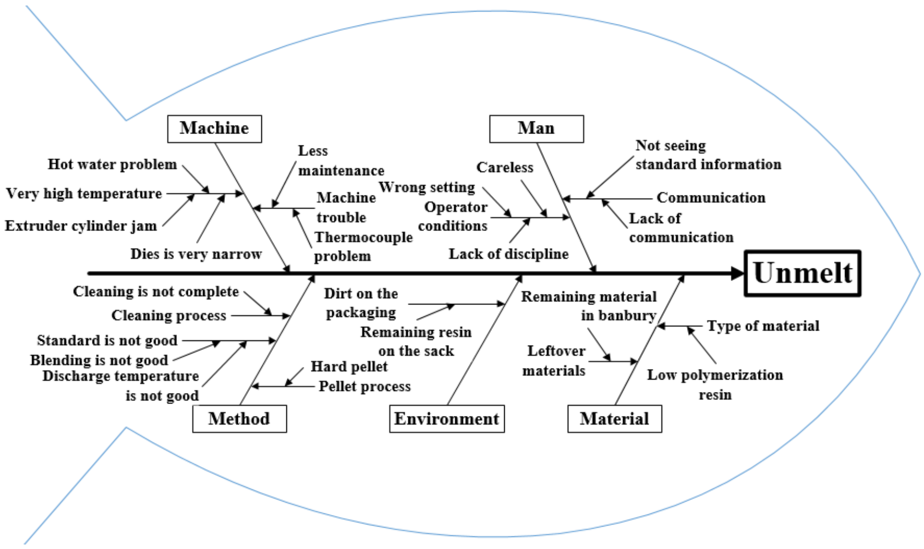


Figure 8. Fishbone Diagram of Unmelt

After identifying the problem with the Fishbone Diagram, then looking for improvement priorities with FMEA analysis through RPN calculations using equation (6). Based on the FGD, the priority rankings that will be improved can be seen in Table 2.

Table 2. Ranking of priorities based on the value of RPN

Type of Defect	Potential Cause of Failure	RPN	Rank
Surface	The kneading process is not strong enough	320	1
Disperse	The blending process time is not long	280	1
	Maximum standard from supplier	280	2

Unmelt	The condition of the cutter is very close to the die	210	1
	Extruder temperature too high	210	2
	Mixing roll temperature is too high	210	3
	The discharge temperature is too high	210	4

3.1.4. Improve

After obtaining priority rankings, then taking corrective actions using the 5W1H method by brainstorming the entire FGD team. The following corrective actions taken using the 5W1H method can be seen in Table 3.

Table 3. Improvement using the 5W1H method

Defect	Causes	Why	What	Where	When	Who	How
Surface	The kneading process is not strong	Material can be kneaded perfectly	Discharge process kneading	Banbury Machine, Extruder Machine	3 Jan 2021	QC staff, Production Foreman, Kneading Operators, Extruding Operators	Raising the upper discharge temperature on the Banbury machine by 5°C, lowering the screw extruder RPM by 3 RPM, using a 100 mesh screen mesh.
Disperse	Less blending time	Materials can be mixed perfectly	Blending process time	Blender Machine	3 Jan 2021	QC staff, Production Foreman, Blending Operators	Adding a blending time of 10 minutes, checking the blender temperature and steam pressure regularly, using a 100 mesh screen mesh.
	Low quality	Some	Improved	Supplier	3 Jan	Purchasin	Replacement of the

	from supplier	material is not dispersed	material quality		21	g Manager	dispersion-causing material
Unmelt	The condition of the cutter is close to the dies	Material is very hot	Adjustment cutter	Extruder Machine	3 Jan 2021	Production Foreman	Regular Extruder Cutter Replacement.
	Extruder temperature is very high	Material is very hot	Material temperature drop	Extruder Machine	3 Jan 21	QC staff, Production Foreman	Lowering Screw and cylinder temperature by 10^{o}C, lowering screw extruder RPM by 3 RPM
	The mixing roll temperature is very high	Material is very hot	Material temperature drop	Mixing Roll	3 Jan 21	QC staff, Production Foreman	Lowering the temperature of the Mixing Roll machine 10^{o}C
	Discharge temperature is very high	Material is very hot	Material temperature drop	Banbury Machine	3 Jan 21	QC staff, Production Foreman	Lowers the top and bottom discharge temperatures by 5^{o}C

- Improvement with Implementation

Based on the proposed improvement with the 5W1H method, the implementation of improvements in the field is carried out as follows:

1. Defect of Surface

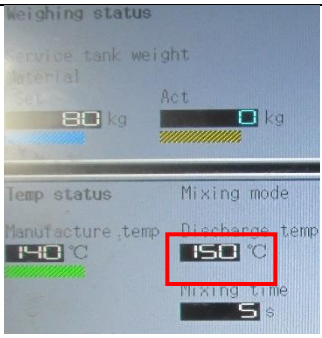
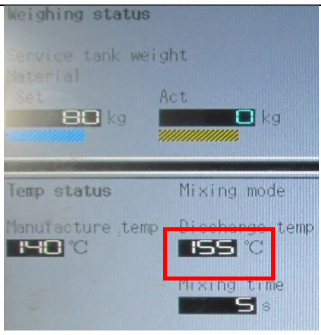
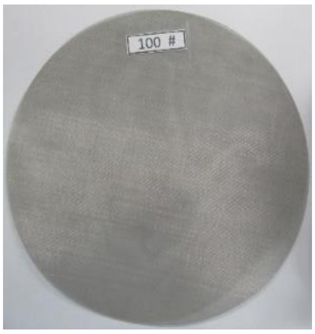
Corrective action:

• Increase the temperature of the Discharge Temperature on the Banbury machine by 5^{o}C

• Lowering the screw extruder's Rotation per Minutes (RPM) by 3 RPM

• Using a 100 mesh screen mesh.

Table 4. Improvement on Surface Defect

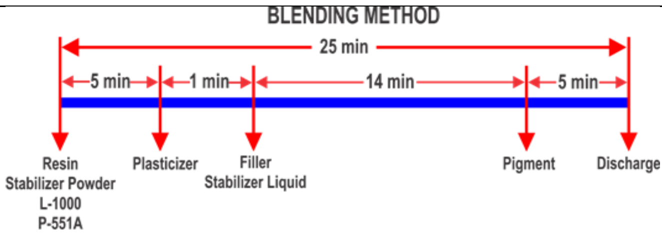
Remark	Discharge Temperature	RPM screw extruder	Screen mesh
Before			
After			

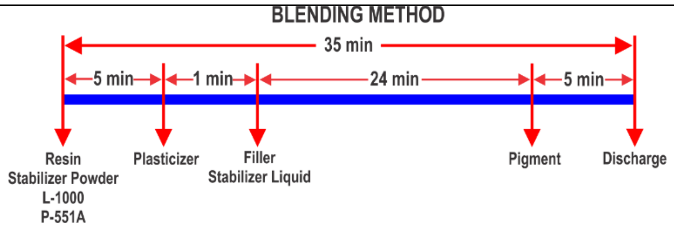
2. Defect of Disperse

Corrective action:

- Increase the blending time by 10 minutes.
- Using a 100 mesh screen mesh.
- Check the blender temperature and steam pressure regularly.
- Replacement of material causing dispersion

Table 5. Improvement on Disperse Defect

Remark	Figure	Different
Before		Blending method: 25 min

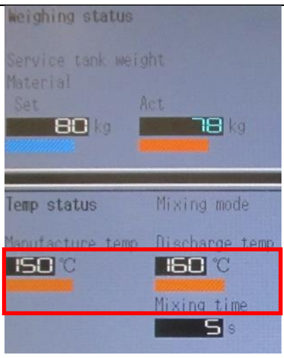
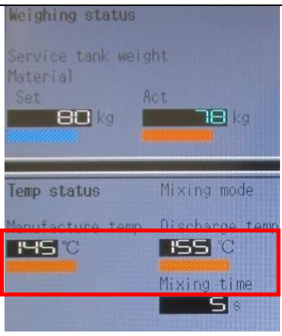
After		Blending method: 35 min

3. Unmelt

Corrective action:

- Lowering the Manufacture Temperature and Discharge Temperature on the Banbury 5°C.
- Lowering the screw and cylinder extruder temperature by 10°C
- Lowering the screw extruder's RPM by 3 RPM
- Lowering the temperature of the Mixing Roll machine by 10°C
- Replace the Extruder Cutter regularly.

Table 6. Improvement on Unmelt Defect

Remark	Banbury machine temperature	Screw temperature	Cylinder Extruder	Mixing Roll temperature
Before				
After				

After the implementation of the improvement, a re-measurement is carried out to determine the effect after the repair. Measurements were made by calculating the value of DPO, DPMO and sigma level after repairs for 6 months of work. The following calculation results can be seen in Table 7.

Table 7. Calculation Results of DPMO and Sigma Level After Improvement

Month	Total Production	Defect	CTQ	DPU	DPO	DPMO	Sigma Level
Jan	3,093,135	2,488	7	0.001	0.0001149	115	5.18
Feb	3,040,004	7,461	7	0.002	0.0003506	351	4.89
Mar	3,619,764	5,219	7	0.001	0.000206	206	5.03
Apr	2,824,308	4,285	7	0.002	0.0002167	217	5.02
May	1,958,114	4,637	7	0.002	0.0003383	338	4.90
Jun	3,106,294	7,055	7	0.002	0.0003245	324	4.91
Total	17,641,619	31,145	7	0.002	0.0002522	252	4.98
Average	2,940,270	5,191	7	0.002	0.0002522	252	4.98

Based on Table 7, it can be seen that the average value of DPMO after corrective action for 6 months is 252. This DPMO value decreased by 657 compared to the value of DPMO before corrective action which was 909. Furthermore, the Sigma value after corrective action for 6 months was 4.98. This Sigma value increased by 0.36 compared to the Sigma value before corrective action, which was 4.62

3.1.5 Control

In the control phase, documentation of corrective actions that have been taken by making changes to operational standards, work instructions and procedures. This is done as a preventive measure so that quality problems do not occur again. The control phase is carried out by making General Condition Standard (GCS), changing work instructions, changing procedures and conducting QC patrols once a month.

1. General Condition Standard (GCS)

Corrective actions were taken such as increasing the discharge temperature in the Banbury machine, increasing the blending time, decreasing the screw and cylinder extruder temperature, screw extruder RPM, decreasing the surface mixing roll temperature and using a 100 mesh screen standardized into the GCS. GCS is made by the Quality Control department with full authority, the production department can view GCS to prepare machine operating conditions. Before production starts, the production foreman checks the operating conditions of the machine according to the GCS and writes it down in the Production Report form. GCS contains all parameters that must be considered by operators and production foremen before and during the production process on certain grade items. The complete GCS can be seen in Figure 9.

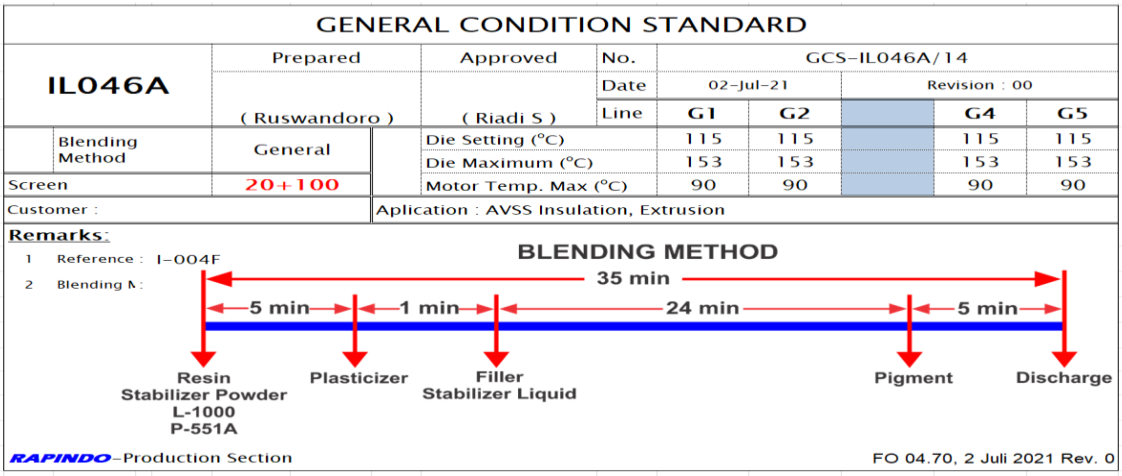


Figure 9. General Condition Standard (GCS) after improvement.

2. Work Instructions and Procedures

Corrective actions taken in the form of changes in the work order such as changes in the cleaning process, processes for materials that fall under the mixing roll, the use of 150 mesh screens are standardized in the Work Instruction number IK 04.06 on the Mixing Process.

3. Checklist

Corrective actions were taken by adding a check sheet related to the machine such as replacing the extruder cutter and cleaning the Banbury Drop Door regularly. Repairs are standardized by making periodic maintenance lists.

4. Quality Control (QC) Patrol

QC patrols are carried out so that corrective actions taken can be controlled continuously. All GCS, work instructions, procedures, periodic maintenance lists can be applied and carried out following with the SOP that is formed and controlled by QC Patrol. QC patrol is carried out once a month, attended by the Manager and QC and Production staff. The results of the QC patrol will be discussed in a special QC Patrol meeting and will be distributed to the relevant departments.

3.2. Practical Implication

Based on improvements by exploring quality problems thoroughly in the PVC Compound production process, significant results were obtained. The results of improvements can increase productivity which has an impact on increasing company profits. This study has proven that product defects have decreased by 46% within 6 months when compared to the average defect product in 2020. The PVC Compound industry always leads to an increase in productivity as a measure of the success of a company. Productivity management needs to be improved with the main goal of empowering minimal resources to get maximum results.

3.3. Comparison with Previous Research

Quality improvement with the DMAIC method can reduce the three biggest defects that have an impact on increasing the sigma level. Based on these results, the company obtains economic benefits which are measured in improving the level of defects. The results of this study are in line with Zaman & Zerin (2017);Bharara et al. (2018); Setiawan & Setiawan (2020) research that the DMAIC method is also able to reduce the rate of defect rates. Most of the manufacturing industry is concerned with low quality which has an impact on the loss of customer satisfaction. Based on Rochman & Agustin (2017) research, to remain consistent, improvements are needed that are supported by top management.

4. Conclusion

This study aims to reduce the level of defects in the production of PVC Compound. This research provides a standard to be applied and controlled during the production of PVC Compounds. The results showed that the DPMO value decreased, while the sigma value increased. The conclusion is that the DMAIC method can reduce the level of defects in the PVC Compounds Industry.

Future research can broaden the perspective of the study by combining DMAIC improvement with sustainable lean manufacturing. In addition to reducing the level of defects, the company will also get a lean production system.

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