DATA ANALYTICS AND APPLIED MATHEMATICS
E-ISSN: 2773-4854
VOLUME 5, ISSUE 2, 2024, 28 – 34
DOI: https://doi.org/10.15282/daam.v5i2.12999

RESEARCH ARTICLE

Application of statistical quality control technique: Applications in the silicone manufacturing industry

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ABSTRACT - Nowadays, silicone rubber material is used for the manufacturing of a wide range of automotive applications, electrical and electronic applications, lighting applications, medical and healthcare applications, cookware, etc. leading to rapid growth in the silicone rubber subsector. Quality-related problems were the major obstacle that leads to customer complaints. Therefore, it is important to review the quality control procedures for the silicone rubber products. In this article, the objectives are mainly focused on the study of the process stability in the ABC Industrial Sdn. Bhd. using statistical quality control tools, the analysis of the most frequently occurring types of defects and the identification of the possible causes of the defects. The result of the studies showed that both filling and packing processes in ABC Industrial Sdn. Bhd. are statistically control. Secondly, the most frequently occurring types of defects identified in both filling and packing process in ABC Industrial Sdn. Bhd. are folding issue at the end of tube, followed by inconsistent filling weight, leaking, seal too tight, mixed colour and wrong tube issues. The possible causes consisted of new operator, careless, lack of focus during work, supplier non-conformance, defective raw material, lack of expert to setup machines, wear and tear, aging of machines, poor working environment, lack of supervision and training, and unclear standard operating procedures (SOPs). Results are beneficial and useful for silicone rubber manufacturing sector for continuous improvement by applying statistical quality control techniques.

ARTICLE HISTORY

Received	:	1st July 2024
Revised	:	15th Aug 2024
Accepted	:	15th Sept 2024
Published	:	30th Sept 2024

KEYWORDS
Quality control
Silicone rubber
Statistical quality control techniques
Process stability
Continuous improvement

1. INTRODUCTION

Silicone is a high-performance elastomer with both viscosity and elasticity and with weak intermolecular forces; therefore, it can be moulded into custom shapes and designs. Due to its high flexibility properties and low-cost pricing, silicone is widely used in various industries such as automotive, construction, household, etc. Silicones such as silicone rubbers, epoxy, adhesives, sealants, and chemical thread lockers enhance part performance and allow the development of new products with improvements that are sensitive to manufacturing costs [1]. Nowadays, the silicone rubber material is used for the manufacturing of a wide range of automotive, electrical and electronic, lighting, medical and healthcare applications, cookware, etc. This indicates that the silicone rubber subsector has grown considerably fast.

In 2020, the outbreak of Coronavirus Disease 2019 (COVID-19) impacted the rubber industry, with global rubber production decreasing by five percent, amounting to 27.4 million metric tons. The global synthetic rubber market size was estimated to be 19.1 billion U.S. dollars in 2021 and is forecasted to grow to 23.2 billion U.S. dollars by 2026 [2]. In May 2021, the price of rubber at the Singapore Commodity Exchange was 2.29 U.S. dollars per kilogram, having recovered from a low of 1.33 U.S. dollars per kilogram in April 2020 during the COVID-19 peak. In 2020, synthetic rubber production accounted for 53 percent of the global rubber supply [2].

ABC Industrial Sdn. Bhd. is a wholly owned Malaysian company located at Indera Mahkota Industrial Area, Kuantan, Pahang. It was established in 2003 and specializes in the product development, manufacture, sales, supply, and distribution of silicone rubber and other chemical-related products.

It is undeniable that the physical appearance of the packaging material and raw material must meet the needs of the customer. However, due to the fast-curing time properties of silicone rubber, it is not possible to rework. Hence, this issue leads to high rejection in silicone rubber. Aside from that, over the years, ABC Industrial Sdn. Bhd. faces several issues, with quality-related problems being the major obstacles that led to customer complaints. Therefore, it is important to review the quality of the silicone rubber products made by this company.

This study embarks on the following research objectives which are to study the process stability in ABC Industrial Sdn. Bhd. is using statistical quality control tools to analyse the most frequently identified types of defects using Pareto analysis and to identify the possible causes of the defects using Cause and Effect Analysis.

The study focuses on the evaluation of the quality performances in the process of manufacturing silicone products over several years in the company by taking a constant sample size of 100 units of silicone rubber, rejection data in both

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the filling and packing process that were recorded daily from 1st until 31st March 2023. Apart from the rejection data, one-month data for the quality-related issues were collected, along with their frequency of occurrence. The major factors that cause rejections of non-conforming silicone rubber products in the production process were identified as well.

In summary, the silicone rubber industry plays a significant role in the construction and other manufacturing industries, as the silicone rubber and epoxy products are specially formulated for high torque applications. Hence, the quality of silicone rubber products provided by the ABC Industrial Sdn. Bhd. would bring an impact on the customers, especially on their satisfaction.

2. METHODOLOGY

2.1 Research framework

The following is the research process adopted in this study.

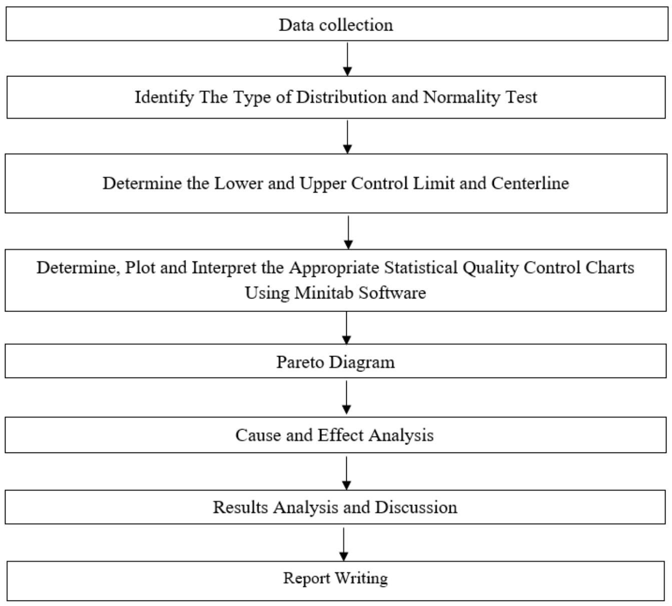

Figure 1. Flow chart of the research process

Most of the statistical methods, such as correlation, regression, and experimental design, are based on one basic assumption, that the observation follows a normal (Gaussian) distribution, as it is assumed that the populations from which the samples are collected are normally distributed. For this reason, the inferential methods require checking the normality assumption [3], and graphical methods provide powerful diagnostic tools for confirming these assumptions. Generally, histograms, P-P plots, and other variants of probability plots are usually applied for the normality assumption [3]. In this study, [4] proposed a test based on empirical distribution by extending the work of [5], and this test is generally known as the Anderson-Darling normality test.

2.2 Shewhart control chart

In this study, the individual measurement data were collected from ABC Industrial Sdn. Bhd. Based on the raw data collected, the Shewhart control charts shall be constructed to determine whether the process of measurement is under statistical control. The calculation of the process means ($\bar{x}$) is shown in equation 1 [6].

$$\bar{x} = \frac{\sum_i^m \bar{x}_m}{m} \tag{1}$$

2.3 np chart

In statistical quality control, the np chart is commonly used for the evaluation of process stability when the number of defectives is monitored. Aside from that, np chart is also useful in tracking the number of defective units in a sample of units. The np chart requires a fixed sample size. The upper control limit (UCL), centre line (CL), and lower control limit (LCL) formulas for np charts are stated as equations 2–4 [6].

$$\text{LCL} = n\bar{p} - 3\sqrt{n\bar{p}(1-\bar{p})} \tag{2}$$

$$\text{CL} = n\bar{p} \tag{3}$$

$$\text{UCL} = n\bar{p} + 3\sqrt{n\bar{p}(1-\bar{p})} \quad (4)$$

2.4 Pareto diagram

Pareto analysis quality tools are widely used to arrange data according to the order of importance. In this study, a Pareto diagram was used to analyse the most frequent types of defects.

2.5 Cause and effect analysis

Cause and effect (C&E) analysis usually results from a brainstorming session to identify and isolate the causes of a problem. The C&E diagram helps to lead to the root cause of the identified problem [7]. Brainstorming is a tool used by teams to bring out the ideas of each individual and present them in an orderly fashion to the rest of the team. The key ingredient is to provide an environment for creative and unrestricted exploration of solutions to problems [7].

3. RESULTS AND DISCUSSION

The current study mainly focuses on the customer returns due to process issues. Hence, data on rejection of silicone rubber products for both filling and packing processes in the ABC Industrial Sdn. Bhd. Thirteen quality-related rejection issues in total were collected for the research which are, inconsistent filling weight, folding issue at the end of tube, cap not fitted properly, wrong machine nozzle applied, mixed colour of raw materials, mixed product card used, wrong filling tube, missing pieces of products, leaking issue, seal too tight, wrong blister used, multiple nozzles in blister and empty packing found in blister. The major factors that cause rejections of non-conforming silicone rubber products in the production process were identified as well.

3.1 Normality test

Normality tests, i.e., Anderson-Darling, probability plot, and histogram, were applied for the rejection dataset in both the filling and packing processes. If the p-value is less than 0.05, the null hypothesis is rejected and concluded that the data is not normally distributed.

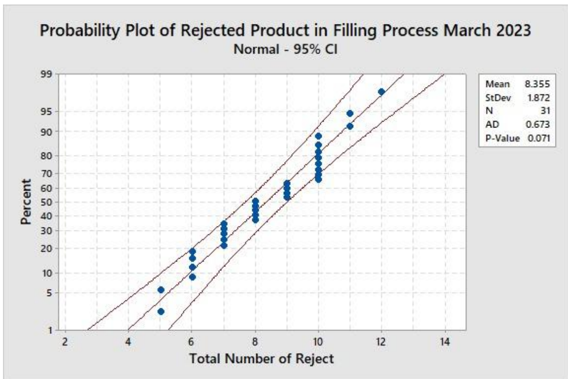

Figure 2. Probability plot of rejected product in the filling process, March 2023

Figure 2 displayed the probability plot for the rejection dataset in the filling process. As observed from the plot, the points in the following normal probability plot follow the fitted line well. The normal distribution appears to be a good fit to the data. Besides that, the p-value obtained was 0.071, implying that the filling rejection data follows a normal distribution with $\alpha = 5$ %.

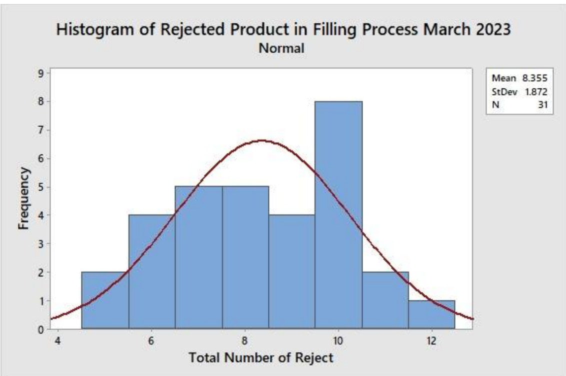

Figure 3. Histogram of rejected product in the filling process, March 2023

Figure 3 displayed the histogram for the rejection dataset in the filling process. As observed from the histogram, all the normal curves are symmetric. Hence, the filling rejection datasets could be concluded as normally distributed.

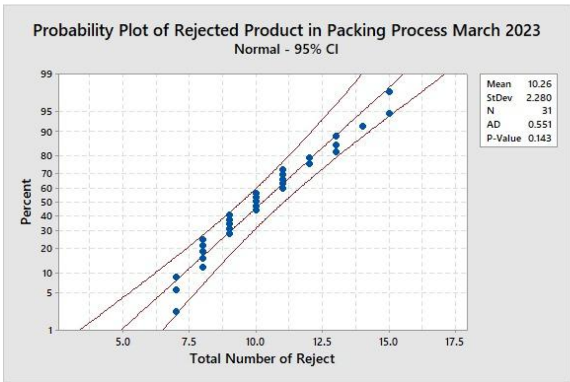

Figure 4. Probability plot of rejected product in packing process, March 2023

Figure 4 displayed the probability plot for the rejection dataset in the packing process. As observed from the plot, the points in the following normal probability plot follow the fitted line well. The normal distribution appears to be a good fit to the data. Besides that, the p-value obtained was 0.143, which is greater than 0.05. With this situation, it was assumed that the packing rejection data fitted a normal distribution with α = 5 %.

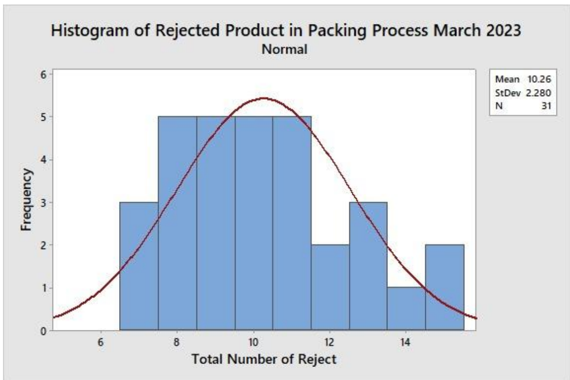

Figure 5. Histogram of rejected product in packing process, March 2023

Figure 5 displayed the histogram for the rejection dataset in the packing process. As observed from the histogram, all the normal curves are symmetric. Hence, the packing rejection datasets could be concluded as normally distributed.

3.2 np chart

Since both the filling and packing rejection data are normally distributed, the most appropriate statistical control chart shall be identified. In this study, the np control chart is the most appropriate control chart as the data showed that the number of defective items in a group of items is constant over time.

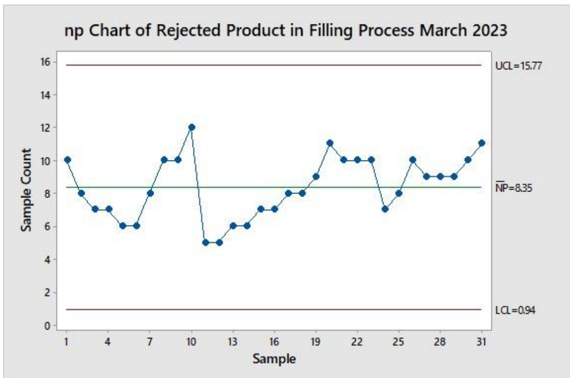

Figure 6. np control chart of rejected product in filling process, March 2023

Figure 6 displayed an np control chart of rejected product in the filling process. Based on the figure, the upper control limit, centre line, and lower control limit are 15.77, 8.35, and 0.94, respectively, and it shows that all the sample points are randomly scattered and fall in between both upper and lower control limits. The filling process in ABC Industrial Sdn. Bhd. is statistically in control.

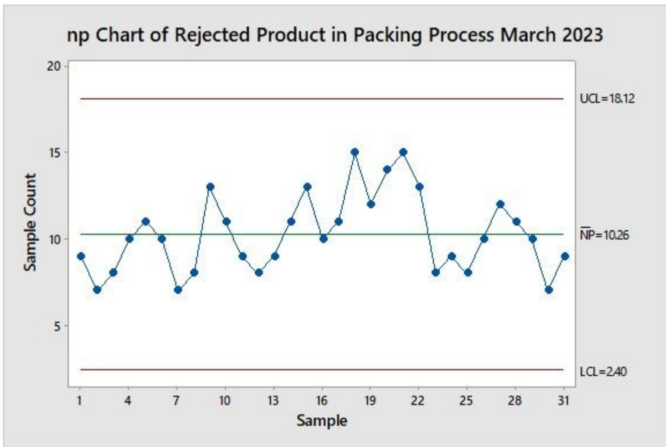

Figure 7. np control chart of rejected product in the packing process, March 2023

Figure 7 displayed an np control chart of rejected product in the packing process. Based on the figure, the upper control limit, centre line, and lower control limit are 18.12, 10.26, and 2.40, respectively, and it shows that all the sample points are randomly scattered and fall between both upper and lower control limits. Therefore, the packing process in ABC Industrial Sdn. Bhd. is statistically in control.

3.3 Pareto analysis

The Pareto principle is a 20/80 rule, which states that: "20 percent of the problems have 80 percent of the impact" [8]. This research conducted a Pareto analysis of the filling and packing process in ABC Industrial Sdn. Bhd. The Pareto Analysis states that 80% of quality problems in the end product or service are caused by 20% of the problems in the production or service processes. Table 1 shows the types of defects with their frequency of occurrence in both filling and packing processes.

Table 1. Types of defects with their frequency of occurrence in both the filling and packing processes

Type of defects	Frequency	Percentage of defective
Folding issue at the end of the tube	213	21.54%
Inconsistent filling weight	186	18.81%
Leaking	158	15.98%
Seal too tight	92	9.30%
Mixed colour	79	7.99%
Wrong tube	66	6.67%
Cap not fitting	58	5.86%
Empty packing	37	3.74%
Mixed card	34	3.44%
Multiple nozzle	22	2.22%
Wrong blister	17	1.72%
Wrong machine nozzle	15	1.52%
Missing pieces	12	1.21%

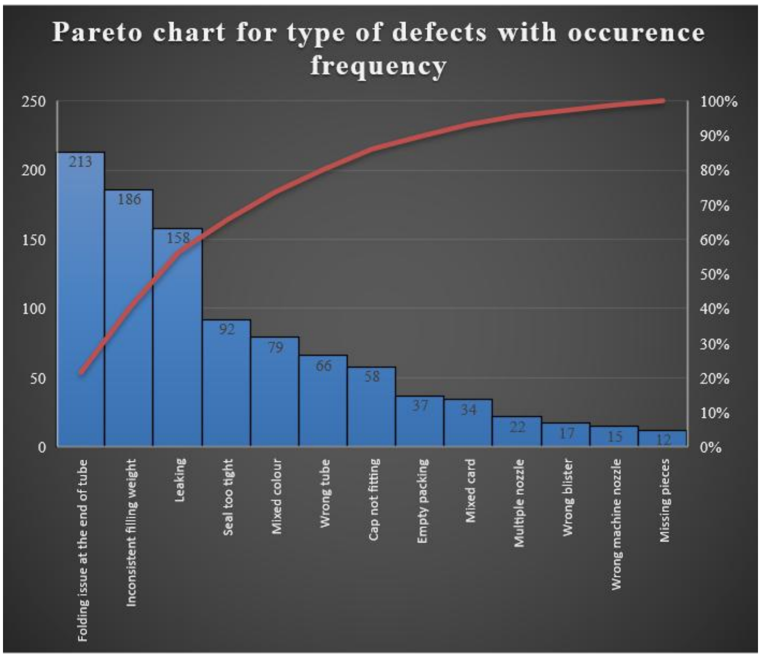

Figure 8. Pareto chart for types of defects with occurrence frequency

The first attempt is to find the type of defects that occur most frequently and then rank them accordingly. 13 types of defects in total were identified that are responsible for the instability of both filling and the packing processes. The Pareto chart shown in Figure 8 revealed that the six defect types (folding issue at the end of the tube, inconsistent filling weight, leaking, seal too tight, mixed colour, and wrong tube) are the vital few that result from 80.28% of the total problems in both the filling and packing process. In other words, if these six types of defects are alleviated, the company can resolve 80.28% of its problems.

3.4 Cause and effect analysis

Next, cause and effect analysis (C&E) aids in identifying the problem's underlying causes, while Pareto analysis aids in prioritising the most urgent issues [7]. The quality improvement team created the C&E diagram in Figure 9 through brainstorming meetings with the participation from operators involved in the production line. During the brainstorming session, 5M concepts have been taken into consideration. 5M concepts, which is also known as the Ishikawa Diagram, is a management tool that aims to analyse the factors and causes of a known problem. The 5M stands for: Machine (equipment), Medium (environment), Method (process), Material (raw materials), Man (workforce). The C&E diagram highlights the key elements that can result in silicone rubber being rejected during the manufacturing process in the company under study.

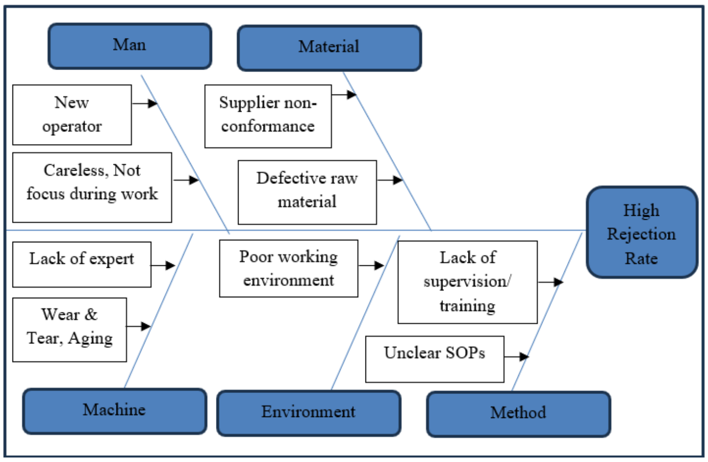

Figure 9. Cause and effect diagram of high rejection rate

4. CONCLUSIONS

All three objectives for this study are met and fulfilled. Since all the data plotted in both filling and packing processes are within the upper and lower control limits, it can be concluded that the filling and packing process in the ABC Industrial Sdn. Bhd. is statistically in control. Secondly, the most frequently occurring types of defects that had been identified in both the filling and packing processes in ABC Industrial Sdn. Bhd. are folding issues at the end of the tube, inconsistent filling weight, leaking, seal too tight, mixed colour, and wrong tube. In order to resolve and overcome the type of defects, the C&E diagram was plotted to identify the possible causes of the defects by implementing the 5M concepts. The possible causes consisted of a new operator, carelessness, not focusing during work, supplier non-conformance, defective raw material, a lack of expertise to set up machines, wear and tear, aging of machines, a poor working environment, lack of supervision and training, and unclear Standard Operating Procedures (SOPs).

Although the ABC Industrial Sdn. Bhd. is aware of its main obstacles; Pareto Analysis should be utilised before other methods to identify the critical problems to be addressed in the company's operations. The ineffective use of cause-and-effect diagrams necessitates a need to revamp corporate standards for statistical quality control at ABC Industrial Sdn. Bhd. The Design of Experiment (DOE) method must be encouraged for usage with SPC instruments. By doing this, the understanding of SPC tools and their advantages to the quality deployment can be further empowered and realised.

ACKNOWLEDGEMENTS

Institution(s)
All the authors would like to express their gratitude to Universiti Malaysia Pahang Al-Sultan Abdullah for the facilities.

Fund
This research was conducted independently and funded solely by the authors, with no external financial support.

Individual Assistant
NA

AUTHOR CONTRIBUTIONS

Jia Xing Teo (Conceptualization; Methodology; Visualization; Writing- original draft; Resources), Mohd Rashid Ab Hamid (Methodology; Writing- review and editing; Supervision).

DECLARATION OF ORIGINALITY

The authors declare no conflict of interest to report regarding this study.

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