East Asian Journal of Multidisciplinary Research (EAJMR)
Vol. 3, No. 7, 2024 : 2785 - 2802

Quality Control Using Statistical Processing Control (SPC) Method on Tensile Testing Results of Metallic Materials

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A R T I C L E I N F O

Keywords: Tensile Testing, Quality Control

Received : 03, June
Revised : 18, June
Accepted: 19, July

A B S T R A C T

This study aims to evaluate the quality of tensile testing conducted at the Mechanical Engineering Laboratory of Politeknik Negeri Medan. Based on the results of attribute inspection, there were 42 units of material defects with a $\overline{P}$ value of 0.124260355. The Upper Control Limit (UCL) was 0.415734865, and the Lower Control Limit (LCL) was 0.0167214 or 0. The subsequent check sheet showed that 34 test specimens did not meet the standard. The P value was 0.0100591716, the UCL was 0.03631557869, and the LCL was 0.00362 or 0. The next check sheet revealed 25 failed tests with a P value of 0.0073964497, a UCL of 0.0299413849, and an LCL of -0.0151484 or 0.

DOI prefix: https://doi.org/10.55927/eajmr.v3i7.9482
ISSN-E: 2828-1519
https://journal.formosapublisher.org/index.php/eajmr

INTRODUCTION

Technological advancement is inevitable, and we should contribute to every development and progress in this era of industrial revolution 4.0 (Putra et al., 2023). The material and manufacturing industries are currently experiencing rapid growth and continuous innovation (Attaqwa et al., 2021). This is driven by advancements in technology and the development of new materials (Fan et al., 2023). The commitment to innovation has resulted in various types of products that serve both passive and active users. This increases the quality requirements of products and forces manufacturers to raise their quality standards.

The advancement of manufacturing processes in the service and production sectors naturally increases the demand for raw materials, not only in terms of quantity but also quality, to prevent errors and defects during production (Howard, 2003). The quality of materials must meet requirements such as toughness, hardness, durability, and corrosion resistance, among others, to ensure that the product is secure and economical.

Production management and quality control are essential elements in achieving high-quality products (Mitra, 2012). By adopting an efficient management system, companies can enhance customer satisfaction, reduce costs, build a positive image, and increase profits. herefore, establishing product quality is a crucial aspect in the manufacturing industry. This can be achieved through careful and accurate control in managing and analyzing the collected data. To ensure product quality, statistical quality control methods need to be used.

In the industry, Statistical Process Control (SPC) is an effective method for detecting defects and ensuring product quality. This research aims to observe the tensile testing results using the Statistical Process Control (SPC) method. Therefore, the researcher will evaluate the quality of tensile testing conducted by the Mechanical Engineering Program students at Politeknik Negeri Medan, or more comprehensively: a) Evaluating the quality of tensile testing results in the Mechanical Engineering laboratory at Politeknik Negeri Medan. b) Applying the SPC method to analyze the data from tensile testing. c) Identifying potential issues related to the quality of tensile testing. d) Providing recommendations to enhance the quality of tensile testing in the future, both for students and the industry.

THEORETICAL REVIEW

Sampling Data from Tensile Testing

Tensile testing is a method to measure the mechanical properties of materials by applying tensile force until the material fractures (Davis, 2004). Tensile testing is a type of destructive testing, where after the specimen breaks, the modulus of elasticity, tensile strength, and tensile stress are analyzed. This testing has been conducted for a long time and remains a classical method that is highly relevant today. The machine used for tensile testing is shown in the image below.

Figure 1. Tensile Testing Machine at the Mechanical Engineering Laboratory, Politeknik Negeri Medan

In the tensile testing process, it is important to use standard specimens. The tested specimens exhibit characteristics as seen in the image below, which represent the testing standards. This research adopts the ASTM-E8 standard (Standard et al., 2013) or as we can see in the image below.

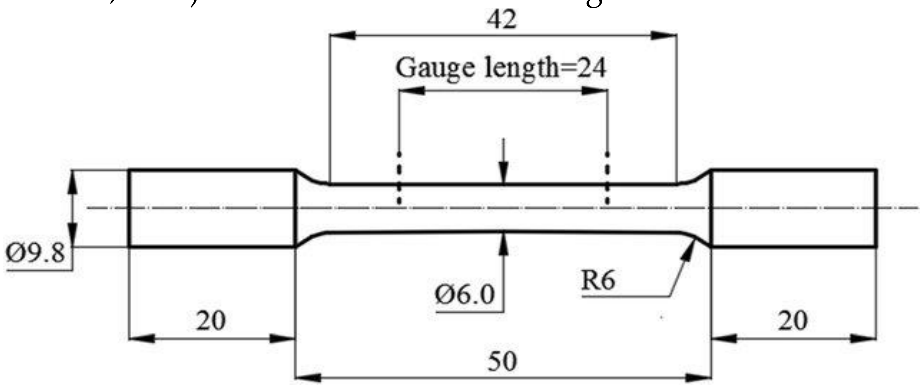

Figure 2. ASTM-E8 Specimen

Figure 3. Tensile Testing Specimen

The data collected in this study are the results of tensile testing obtained from student laboratory activities. The sampling method in this research follows the Issac and Michael equation (Mitra, 2012).

$$S = \frac{\lambda^2 \times N x P \times Q}{d \times (N-1) + \lambda^2 \text{ x P x Q}} \quad (1)$$

Where :
S : Sample size
λ^2 : The level of significance is 5 % (z = 1.645)
N : Population size
P : Proportion (0,5)
Q : Precision (0,5)
d : Mean difference (0,05)

METHODOLOGY

The research method applied in this study is the experimental method with numerical data collection. The process involves the preparation of equipment and materials for tensile testing, as illustrated in the research diagram below

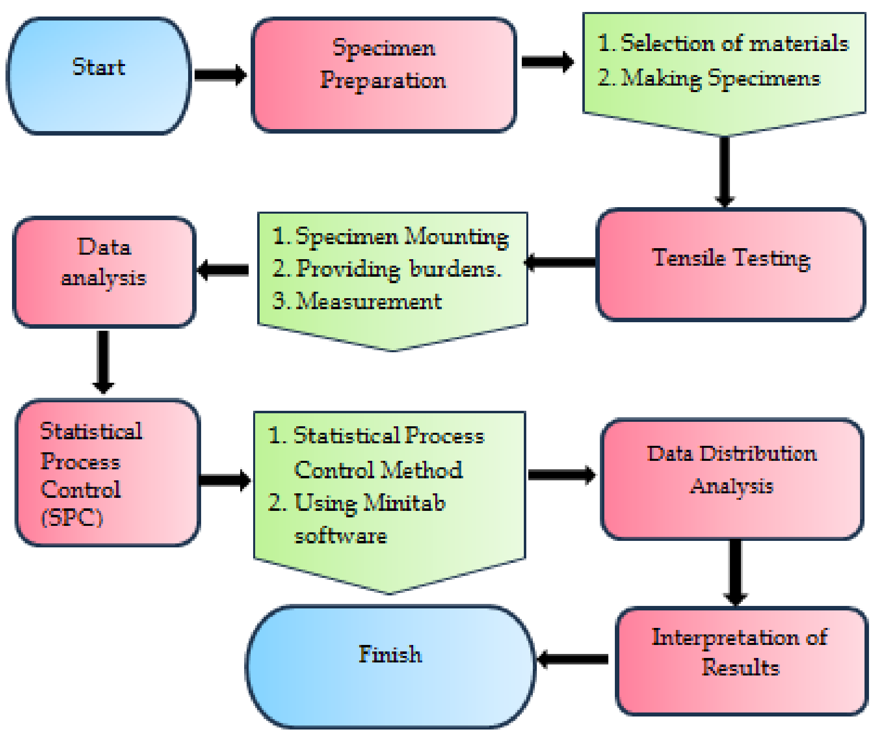

Figure 4. Research Flow

Statistical Process Control (SPC) Data Analysis

The Statistical Process Control (SPC) method is a commonly used statistical approach in research and product development (Leavengood & Reeb, 2015). This method is applied in this study according to the established procedures. In the context of this research, SPC is used by following the appropriate formulas to monitor and control variability, thus ensuring the quality of the research product. The data analysis phase in this study will use three tools available in Statistical Process Control. The three tools are as follows.

1. *Check Sheet*

A Check Sheet is a useful tool for systematically and structurally collecting production data, including tensile testing data in this context. A check sheet helps in recording important information about the process, particularly the results of tensile testing.

2. *Pareto Diagram*

The Pareto Diagram, or Pareto Chart, is a bar graph that depicts the cumulative comparison of each type of data against the total data. Simply put, this diagram shows the contribution of each category or cause of the problem to the total issues (Down, 2005). This is a highly effective tool for identifying and prioritizing the most important factors influencing a particular outcome.

3. *P-Chart Control Diagram*

Control charts are used to monitor the production process and determine if there are any deviations beyond control limits. In establishing control limits, this step must be identified using specific formulas (Ika Putri et al., 2016). In this research, variable inspection is also utilized to identify testing defects and classify them, which is referred to as the P-Chart.

- Determining the fraction of defect

$$\overline{\mathrm{P}} = \frac{\Sigma_x}{\Sigma n} \quad \text{(2)}$$

Where:
$\overline{\mathrm{P}}$: Average fraction of defects
Σx : Number of defective products
Σn : Total production

- Determining the Center Line

$$\mathrm{CL} = p = \frac{\Sigma np}{\Sigma n} \quad \text{(3)}$$

Where :
CL : Central Line
Σnp : Total number of defects
Σn : Total number inspected

- Determining the Upper Control Limit (UCL) for the P-Chart

$\mathrm{UCL} = \overline{\mathrm{P}} + \mathrm{Z} \times \sigma\overline{\mathrm{P}}$ ....(4)

Where :
UCL : Upper Control Limit
$\overline{\mathrm{P}}$: Average defect rate
Z : Normal standard deviation (3=99,73%)
$\sigma\overline{\mathrm{P}}$: $\frac{\sqrt{\overline{\mathrm{P}}(1-\overline{\mathrm{P}})}}{\mathrm{n}}$

- Determining the Lower Control Limit (LCL) for the P-Chart

$\mathrm{LCL} = \overline{\mathrm{P}} - \mathrm{Z} \times \sigma\overline{\mathrm{P}}$ ....(5)
Where :
LCL : Upper Control Limit
$\overline{\mathrm{P}}$: Average defect rate
Z : Normal standard deviation (3=99,73%)
$\sigma\overline{\mathrm{P}}$: $\frac{\sqrt{\overline{\mathrm{P}}(1-\overline{\mathrm{P}})}}{\mathrm{n}}$

RESULTS

Sample Data

The available population for this study consists of 250 units of tensile test specimens conducted by students using the ASTM-E8 standard. Out of the 250 units, 130 units are selected as research samples based on the Issac and Michael equation. The steps to determine the sample are as follows:

$$\mathrm{S} = \frac{1{,}65^2 \times 250 \text{ x } 0{,}5 \times 0{,}5}{0{,}05 \times (250-1) + 1{,}65^2 \text{ x } 0{,}5 \text{ x } 0{,}5}$$

$$\mathrm{S} = \frac{169{,}1265}{12{,}45 + 0{,}67650625}$$

$$\mathrm{S} = \frac{169{,}1265625}{0{,}6225 + 0{,}67650625}$$

$$\mathrm{S} = 130{,}398$$

Thus, the total number of tensile testing specimens used in this study is 130 units.

Check Sheet

In this study, a check sheet has been utilized in the initial phase of Statistical Process Control to collect data related to the quality of tensile testing. The data obtained from the check sheet is then processed to aid in analyzing and identifying issues. Three issues can be identified: material defects, non-conforming specimens, and failed tests, or more comprehensively as shown in the table below

Table 1. Results of the check sheet for material defects, non-conforming specimens, and failed tests from February 19th to May 13th, 2024.

No	Observation Time	Sample	Material Defects	Non-Conforming Specimens	Failed Tests
1	February 19, 2024	130	1	1	2
2	February 21, 2024	130	2	1	0
3	February 23, 2024	130	1	0	1
4	March 4, 2024	130	5	0	0
5	March 6, 2024	130	0	2	0
6	March 8, 2024	130	0	3	1
7	March 13, 2024	130	1	1	0
8	March 15, 2024	130	0	5	1
9	March 18, 2024	130	0	1	1
10	March 20, 2024	130	2	0	1
11	March 22, 2024	130	1	2	0
12	March 25, 2024	130	3	1	0
13	March 27, 2024	130	2	0	1
14	April 1, 2024	130	1	4	0
15	April 3, 2024	130	3	0	0
16	April 5, 2024	130	1	3	0
17	April 17, 2024	130	4	0	2
18	April 19, 2024	130	1	1	0
19	April 22, 2024	130	1	0	0
20	April 24, 2024	130	2	2	0
21	April 26, 2024	130	3	0	1
22	April 29, 2024	130	1	1	1
23	May 3, 2024	130	2	2	1
24	May 6, 2024	130	1	3	2
25	May 8, 2024	130	3	0	0
26	May 13, 2024	130	1	1	1
	Total	**3380**	**42**	**34**	**16**

Pareto Diagram

The second stage conducted is to perform analysis and create a Pareto diagram. The Pareto diagram for this research is presented in the table below.

Table 2. The Pareto diagram data for tensile testing

Defect Types	Defect Count	Cumulative Presentation%	Presentation %
Material Defects	42	42%	46%
Non-Compliant specimen	34	76%	37%
Failed test	16	92%	17%
Total	**92**		**100%**

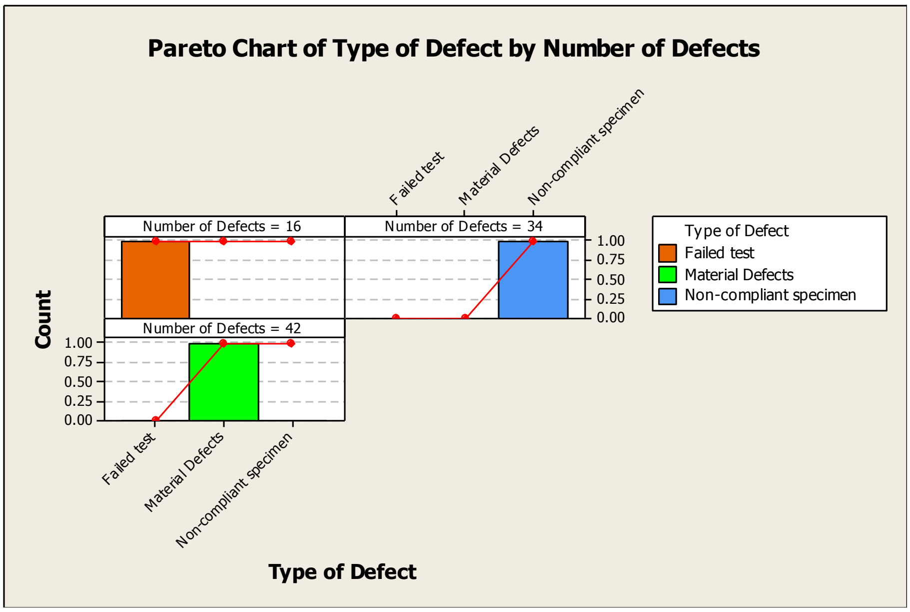

Figure 5. Pareto Diagram of Types of Defects

Based on the Pareto diagram above, we can conclude that the highest defect type during the 26-day testing period is material defect, with a count of 42 units, accounting for 46%. The second highest defect type is non-conforming specimens, with 34 units and a percentage of 37%. The lowest defect type is failed tests, with 16 units, representing 17%.

P-Chart Control Diagram

The next step is to create a control chart. The first control chart used is attribute inspection for the P-Chart. This visual tool is used to monitor the results of tensile testing and ensure that the testing process runs smoothly and meets the established quality standards.

Determine the control diagram for material defects

To effectively monitor the control chart for material defects, it's essential to determine the Upper Control Limit (UCL), Average Defect Proportion ($\overline{P}$), and Lower Control Limit (LCL). These values provide crucial information about the performance of the material being tested and help identify potential material issues. Although this study has obtained the UCL and LCL values from Minitab, it's important to verify them through manual calculations using established formulas. This ensures consistency and accuracy of the data and provides a deeper understanding of the interpretation of these values. The data obtained is as follows:

Table 3. Tensile testing material defect data

No	Observation Time	Sample	Material Defects	p	$\bar{p}$	LCL	UCL
1	February 19, 2024	130	1	0.0077	0.0124	-0.0167	0.0416
2	February 21, 2024	130	2	0.0154	0.0124	-0.0167	0.0416
3	February 23, 2024	130	1	0.0077	0.0124	-0.0167	0.0416
4	March 4, 2024	130	5	0.0385	0.0124	-0.0167	0.0416
5	March 6, 2024	130	0	0.0000	0.0124	-0.0167	0.0416
6	March 8, 2024	130	0	0.0000	0.0124	-0.0167	0.0416
7	March 13, 2024	130	1	0.0077	0.0124	-0.0167	0.0416
8	March 15, 2024	130	0	0.0000	0.0124	-0.0167	0.0416
9	March 18, 2024	130	0	0.0000	0.0124	-0.0167	0.0416
10	March 20, 2024	130	2	0.0154	0.0124	-0.0167	0.0416
11	March 22, 2024	130	1	0.0077	0.0124	-0.0167	0.0416
12	March 25, 2024	130	3	0.0231	0.0124	-0.0167	0.0416
13	March 27, 2024	130	2	0.0154	0.0124	-0.0167	0.0416
14	April 1, 2024	130	1	0.0077	0.0124	-0.0167	0.0416
15	April 3, 2024	130	3	0.0231	0.0124	-0.0167	0.0416
16	April 5, 2024	130	1	0.0077	0.0124	-0.0167	0.0416
17	April 17, 2024	130	4	0.0308	0.0124	-0.0167	0.0416
18	April 19, 2024	130	1	0.0077	0.0124	-0.0167	0.0416
19	April 22, 2024	130	1	0.0077	0.0124	-0.0167	0.0416
20	April 24, 2024	130	2	0.0154	0.0124	-0.0167	0.0416
21	April 26, 2024	130	3	0.0231	0.0124	-0.0167	0.0416
22	April 29, 2024	130	1	0.0077	0.0124	-0.0167	0.0416
23	May 3, 2024	130	2	0.0154	0.0124	-0.0167	0.0416
24	May 6, 2024	130	1	0.0077	0.0124	-0.0167	0.0416
25	May 8, 2024	130	3	0.0231	0.0124	-0.0167	0.0416
26	May 13, 2024	130	1	0.0077	0.0124	-0.0167	0.0416

Total	**3380**	**42**

From the table above, we can determine the average fraction, upper control limit, and lower control limit. To determine the average fraction of defects ($\overline{P}$), we can use the formula:

$$\overline{P} = \frac{\Sigma_x}{\Sigma n} = \frac{42}{130\ x\ 26} = \frac{42}{3380} = 0{,}0124260355$$

After calculating the average fraction of defects ($\overline{P}$), the next step is to determine the Upper Control Limit (UCL) for the P-Chart. UCL is the maximum value tolerated for the proportion of defects in a sample before the process is considered out of control. Before we find the value of UCL, we will calculate the standard deviation of the sampling distribution with the following formula.

$$\sigma\overline{P} = \frac{\sqrt{\overline{P}(1-\overline{P})}}{n}$$

$$\sigma\overline{P} = \frac{\sqrt{0{,}0124260355(1-0{,}0124260355)}}{130}$$

$$\sigma\overline{P} = \frac{\sqrt{0{,}0122716291}}{130}$$

$\sigma\overline{P}$ = 0,009715817

Given that the standard deviation of the sampling distribution is 0.009715817, we can obtain the value of UCL as follows.

$$\text{UCL} = \overline{P} + Z \times \sigma\overline{P}$$

$$\text{UCL} = 0{,}0124260355 + 3\ x\ 0{,}009715817$$

$$\text{UCL} = 0{,}0415734865$$

Then, we can determine the value of LCL as follows:

$$\text{LCL} = \overline{P} - Z \times \sigma\overline{P}$$

$$\text{LCL} = 0{,}0124260355 - 3\ x\ 0{,}009715817$$

$$\text{LCL} = 0{,}0167214155$$

$$\text{LCL} = 0$$

After calculating the Upper Control Limit (UCL), Average Fraction of Defects (P), and Lower Control Limit (LCL), we will use these results to create and interpret the Material Defect Control Chart with the help of Minitab software. The result obtained is shown in the image below.

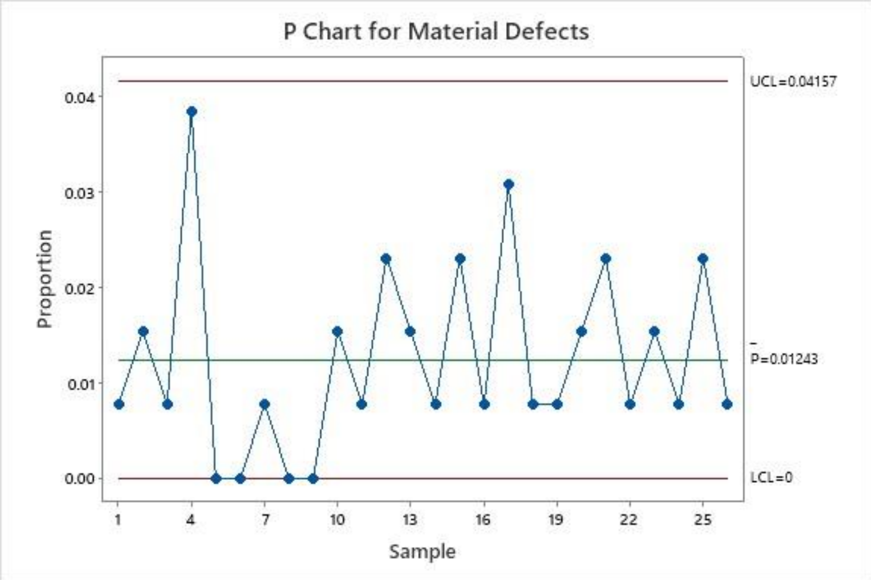

Figure 6. P-Chart for Material Defects

From the above image, we can observe that the tensile testing inspection through the material defect control is still within controlled proportions because none of them exceed the upper control limit of 0.04157 and the lower control limit of 0.

Determining the Non-Conforming Sample Control Chart

The next step is to calculate the UCL and LCL from the specimens tested to determine the control limits. The data obtained is as follows:

Table 4. Data of Non-Conforming Specimens tested according to ASTM-E8

No	Observation Time	Sample	Non-Conforming Specimens	P	p̄	LCL	UCL
1	February 19, 2024	130	1	0.0077	0.0101	-0.0162	0.0363
2	February 21, 2024	130	1	0.0077	0.0101	-0.0162	0.0363
3	February 23, 2024	130	0	0.0000	0.0101	-0.0162	0.0363
4	March 4, 2024	130	0	0.0000	0.0101	-0.0162	0.0363
5	March 6, 2024	130	2	0.0154	0.0101	-0.0162	0.0363
6	March 8, 2024	130	3	0.0231	0.0101	-0.0162	0.0363

7	March 13, 2024	130	1	0.0077	0.0101	- 0.0162	0.0363
8	March 15, 2024	130	5	0.0385	0.0101	- 0.0162	0.0363
9	March 18, 2024	130	1	0.0077	0.0101	- 0.0162	0.0363
10	March 20, 2024	130	0	0.0000	0.0101	- 0.0162	0.0363
11	March 22, 2024	130	2	0.0154	0.0101	- 0.0162	0.0363
12	March 25, 2024	130	1	0.0077	0.0101	- 0.0162	0.0363
13	March 27, 2024	130	0	0.0000	0.0101	- 0.0162	0.0363
14	April 1, 2024	130	4	0.0308	0.0101	- 0.0162	0.0363
15	April 3, 2024	130	0	0.0000	0.0101	- 0.0162	0.0363
16	April 5, 2024	130	3	0.0231	0.0101	- 0.0162	0.0363
17	April 17, 2024	130	0	0.0000	0.0101	- 0.0162	0.0363
18	April 19, 2024	130	1	0.0077	0.0101	- 0.0162	0.0363
19	April 22, 2024	130	0	0.0000	0.0101	- 0.0162	0.0363
20	April 24, 2024	130	2	0.0154	0.0101	- 0.0162	0.0363
21	April 26, 2024	130	0	0.0000	0.0101	- 0.0162	0.0363
22	April 29, 2024	130	1	0.0077	0.0101	- 0.0162	0.0363
23	May 3, 2024	130	2	0.0154	0.0101	- 0.0162	0.0363
24	May 6, 2024	130	3	0.0231	0.0101	- 0.0162	0.0363
25	May 8, 2024	130	0	0.0000	0.0101	- 0.0162	0.0363

26	May 13, 2024	130	1	0.0077	0.0101	-0.0162	0.0363
	Total	**3380**	**34**				

From the data above, we will determine the UCL and LCL of non-conforming specimens for the P-Chart. Before determining the values of UCL and LCL, we will calculate the average fraction of defects, and then determine the standard deviation of the sampling distribution using the formula below.
Calculating $\overline{P}$, the average fraction of defects:

$$\overline{P} = \frac{\Sigma_x}{\Sigma n} = \frac{34}{130 \text{ x } 26} = \frac{34}{3380} = 0{,}0100591716$$

Next, we will determine the standard deviation of the sampling distribution:

$$\sigma\overline{P} = \frac{\sqrt{\overline{P}(1-\overline{P})}}{n}$$

$$\sigma\overline{P} = \frac{\sqrt{0{,}0100591716(1-0{,}0100591716)}}{130}$$

$$\overline{P} = \frac{\sqrt{0{,}0095798456}}{130}$$

$$\sigma\overline{P} = 0{,}00875213573$$

The standard deviation of the sampling distribution obtained is 0.00875213573. Therefore, the value of UCL can be determined as follows:

$\text{UCL} = \overline{P} + Z \times \sigma\overline{P}$
$\text{UCL} = 0{,}0100591716 + 3\, x\, 0{,}00875213573$
$\text{UCL} = 0{,}03631557869$

Then, the value of LCL can be obtained as follows:

$\text{LCL} = \overline{P} - Z \times \sigma\overline{P}$
$\text{LCL} = 0{,}0124260355 - 3\, x\, 0{,}00875213573$
$\text{LCL} = 0{,}0362$
$\text{LCL} = 0$

To deepen the analysis, we distribute the values of UCL, LCL, and $\overline{P}$ to obtain the control chart. The chart is shown in the image below.

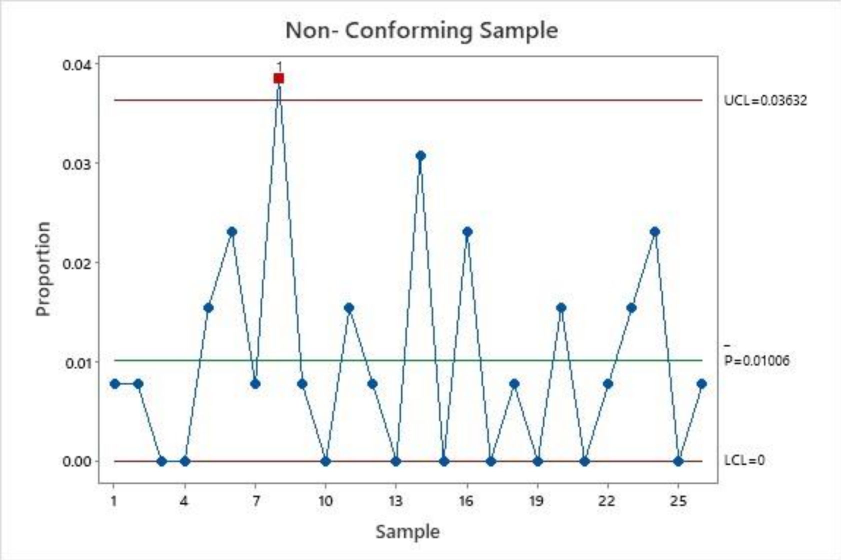

Figure 7. P-Chart for Non-Conforming Sample

From the above diagram, it shows that the value of UCL = 0.0362, LCL = 0 with $\overline{P}$=0.01006. From the graph, we can analyze that there is one testing that passes the control limit or is out of control from the Upper Control Limit, which is the 8th test. Therefore, it needs to be improved by paying attention to the standardization of specimen creation by students. Furthermore, if we look at the other testing graphs, they are still within control or within the control limits.

Determining the Control Chart for Failed Testing

Table 5. Data of Specimen for Failed Testing Control Chart

No	Observation Time	Sample	Failed Testing	p	$\bar{p}$	LCL	UCL
1	February 19, 2024	130	2	0.01538	0.00740	-0.01515	0.02994
2	February 21, 2024	130	0	0.00000	0.00740	-0.01515	0.02994
3	February 23, 2024	130	1	0.00769	0.00740	-0.01515	0.02994
4	March 4, 2024	130	0	0.00000	0.00740	-0.01515	0.02994
5	March 6, 2024	130	5	0.03846	0.00740	-0.01515	0.02994
6	March 8, 2024	130	1	0.00769	0.00740	-0.01515	0.02994
7	March 13, 2024	130	0	0.00000	0.00740	-0.01515	0.02994
8	March 15, 2024	130	1	0.00769	0.00740	-0.01515	0.02994
9	March 18, 2024	130	1	0.00769	0.00740	-0.01515	0.02994
10	March 20, 2024	130	1	0.00769	0.00740	-0.01515	0.02994
11	March 22, 2024	130	0	0.00000	0.00740	-0.01515	0.02994

12	March 25, 2024	130	0	0.00000	0.00740	-0.01515	0.02994
13	March 27, 2024	130	1	0.00769	0.00740	-0.01515	0.02994
14	April 1, 2024	130	0	0.00000	0.00740	-0.01515	0.02994
15	April 3, 2024	130	0	0.00000	0.00740	-0.01515	0.02994
16	April 5, 2024	130	0	0.00000	0.00740	-0.01515	0.02994
17	April 17, 2024	130	2	0.01538	0.00740	-0.01515	0.02994
18	April 19, 2024	130	0	0.00000	0.00740	-0.01515	0.02994
19	April 22, 2024	130	4	0.03077	0.00740	-0.01515	0.02994
20	April 24, 2024	130	0	0.00000	0.00740	-0.01515	0.02994
21	April 26, 2024	130	1	0.00769	0.00740	-0.01515	0.02994
22	April 29, 2024	130	1	0.00769	0.00740	-0.01515	0.02994
23	May 3, 2024	130	1	0.00769	0.00740	-0.01515	0.02994
24	May 6, 2024	130	2	0.01538	0.00740	-0.01515	0.02994
25	May 8, 2024	130	0	0.00000	0.00740	-0.01515	0.02994
26	May 13, 2024	130	1	0.00769	0.00740	-0.01515	0.02994
	Total	**3380**	**25**				

From the available data, we will calculate the Upper Control Limit (UCL) and the Lower Control Limit (LCL) for the non-conforming samples on the P-Chart. Before determining the UCL and LCL values, we first need to calculate the average fraction of defects and the standard deviation of the sampling distribution using the following formulas:

Calculating $\overline{\mathrm{P}}$, the average fraction of defects:

$$\overline{\mathrm{P}} = \frac{\Sigma_{\mathrm{x}}}{\Sigma \mathrm{n}} = \frac{25}{130 \times 26} = \frac{25}{3380} = 0{,}0073964497$$

Next, we determine the standard deviation of the sampling distribution:

$$\sigma\overline{\mathrm{P}} = \frac{\sqrt{\overline{\mathrm{P}}(1-\mathrm{P})}}{\mathrm{n}}$$

$$\sigma\overline{\mathrm{P}} = \frac{\sqrt{0{,}0073964497(1-0{,}0073964497)}}{130}$$

$$\sigma\overline{\mathrm{P}} = \frac{\sqrt{0{,}0073417408}}{130}$$

$$\sigma\overline{\mathrm{P}} = 0{,}0075149784$$

Therefore, the Upper Control Limit (UCL) value can be determined as follows:

$$\mathrm{UCL} = \overline{\mathrm{P}} + \mathrm{Z} \times \sigma\overline{\mathrm{P}}$$

$$\mathrm{UCL} = 0{,}0073964497 + 3\ x\ 0{,}0073964497$$

$$\mathrm{UCL} = 0{,}0299413849$$

Next, the value of LCL is obtained as follows:

$$\mathrm{LCL} = \overline{\mathrm{P}} - \mathrm{Z} \times \sigma\overline{\mathrm{P}}$$

$$\mathrm{LCL} = 0{,}0073964497 - 3\ x\ 0{,}0073964497$$

$$\mathrm{LCL} = -0{,}0151484$$

$$\mathrm{LCL} = 0$$

To perform a more in-depth analysis, the Upper Control Limit (UCL) and Lower Control Limit (LCL) values are plotted on a control chart. This control chart is depicted in the following diagram:

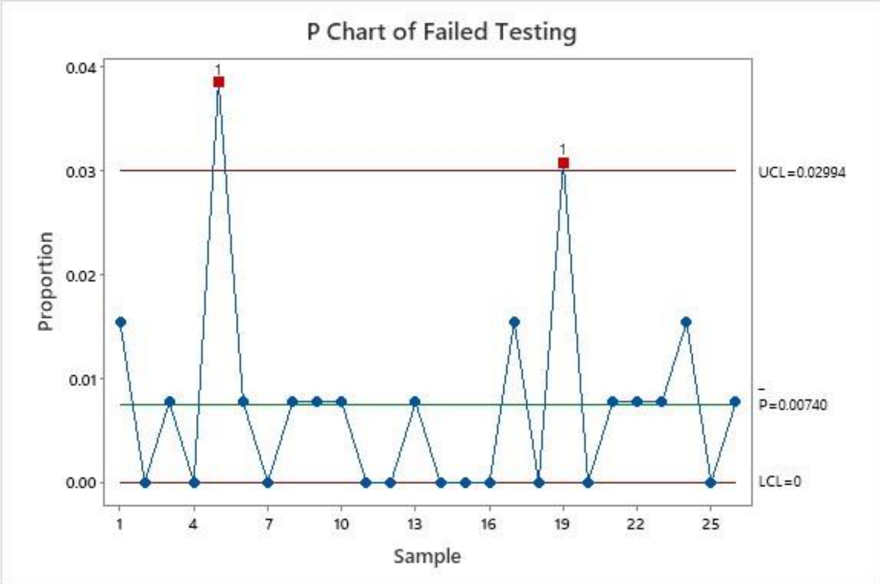

Figure 8. Control Chart for Testing

The control diagram for the failed test inspection in the tensile test found the control limit values UCL = 0.0299, LCL = 0 and $\overline{P}$ = 0.007440. Based on the control diagram above, we can observe that there are two data points that exceed the Upper Control Limit (UCL), namely in tests 5 and 19. This shows that this process requires an in-depth analysis of the causes or factors that influence the predetermined control limits.

CONCLUSIONS

The conclusions drawn from all the tensile testing results conducted by the Mechanical Engineering Laboratory by students of the Mechanical Engineering program at the State Polytechnic of Medan are as follows:

1. Based on the check sheet results, attribute inspection revealed 42 units of material defects with a value of $\overline{P}$ = 0,124260355. Subsequently, the Upper Control Limit (UCL) was calculated as 0.415734865 and the Lower Control Limit (LCL) as 0,0167214 or 0. With analysis of the control chart, the inspection of material defects remains under control, as there are no data points exceeding the UCL and LCL limits.
2. The subsequent check sheet results revealed 34 units of specimens not meeting the standard. From these results, $\overline{P}$=0,0100591716P=0,0100591716 was calculated, with UCL = 0,03631557869 and LCL = 0,0362 or = 0. Observation of the control chart indicates that specimens not meeting the standard exceeded the UCL limit, specifically during the 8th test. Therefore, corrective actions and evaluation.
3. The subsequent check sheet results indicated 25 units of failed tests, with $\overline{P}$=0,0073964497, UCL = 0.0299413849, and LCL = -0,0151484 or = 0. Control chart examination revealed findings that exceeded the control limit or UCL.

RECOMMENDATIONS

Tensile testing is a crucial method for analyzing the strength of materials. By employing material quality control methods, the strength and durability of materials can be ensured. Here are some recommendations for conducting effective tensile testing based on quality control methods:

1. Determine the testing objectives: Establish whether the goal of the test is to determine maximum tensile strength, elastic modulus, or material elongation.
2. Select appropriate test specimens: Ensure that the shape and dimensions of the specimens conform to applicable standards.
3. Prepare testing equipment: Ensure that the tensile testing machine, data processing, and data recording devices are in good condition.
4. Develop testing procedures: Align the testing procedures with the relevant standards and the capabilities of the testing machine.

FURTHER STUDY

This research still has many limitations; therefore, the plan for the next research is to comprehensively monitor the quality of the test results.

ACKNOWLEDGMENT

Thank you very much to all parties who contributed to this research.

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