Elimination of Weld Defects Using Quality Control Tools

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Abstract. This research focuses on addressing challenges within the wheel manufacturing industry's assembly line, particularly post the submerged arc welding process. The welding involves an electrode ignites arc with flux for welding, and critical defects like porosity, blow holes, excessive spatter, cracks, and undercut are identified. Our study aims to minimize these defects through the implementation of quality control tools such as histogram, Pareto diagram, control chart, box plot, run chart, correlation, and scatter diagram (with interpretation of a scatter plot showcasing the defects data). The data collected during this research period serves as the basis for analysis. The overarching goal of this paper is to systematically reduce weld defects, thereby enhancing overall production quality in the wheel manufacturing industry

Keywords: Quality control tool; Weld defects

1 Introduction

The 7 QC Tools, straightforward statistical instruments utilized for troubleshooting across industries, were originally crafted in Japan by Deming and Juran. Considered the most valuable tools, Kaoru Ishikawa affirmed that these 7 tools can effectively tackle 95 percent of all issues. These tools have served as the cornerstone of Japan's remarkable industrial resurgence[1]. In this study, the focus will be on essential tools known as the seven basic quality control tools commonly utilized in numerous software applications[2].These tools include the Cause-and-Effect Diagram, Flowcharts, Pareto analysis, Check sheets, Control charts, Scatter diagram, and Histogram. [3]Their primary purpose is to identify root causes of issues and eliminate them, ultimately leading to improvements in the manufacturing process. Defects in the manufacturing line are analysed through direct observations on the production line and statistical methods.

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2 Literature review

Introduced a novel temporal histogram model and synthesizer that accurately captures individual household electricity and hot water usage behaviour. Using a substantial dataset, the model demonstrates high accuracy in characterizing usage behaviour and predicting future consumption [6]. This study introduces a novel approach for real-time quality control, specifically targeting small shift detection in manufacturing processes. The proposed method involves the fusion of multiple models to enhance the sensitivity and accuracy of detecting subtle deviations in production output. By combining the strengths of different modelling techniques, such as statistical process control (SPC), machine learning algorithms, and data fusion methods, the approach offers a robust solution for early detection of small shifts in process parameters. Through extensive experimentation and validation, the study demonstrates the effectiveness of the multi-model fusion algorithm in improving the reliability and efficiency of quality control systems. The algorithm's capability to promptly identify minor variations in production processes enables timely corrective actions, thereby minimizing defects and enhancing product quality. Overall, the integration of this approach as a real-time quality control tool promises to bolster manufacturing performance and competitiveness[7]. Quality assurance is a critical aspect of manufacturing systems, ensuring that products meet desired standards. One of the latest approaches in this domain is Zero Defect Manufacturing (ZDM), which aims to eliminate defects entirely. In the context of the automotive industry, ZDM is particularly relevant, especially concerning processes like spot welding. Machine learning methods have gained prominence in quality assurance, with techniques such as linear regression and Long Short-Term Memory (LSTM) networks being utilized to predict the quality of spot welds. These methods leverage data from production, including sensor readings and engineering data, to forecast the quality of future welds. Following quality prediction, root cause analysis becomes crucial in understanding why certain spot welds may fail. By identifying the underlying reasons for defects, manufacturers can take appropriate preventive actions to improve quality. The implementation of this approach involves training and validating the machine learning model to ensure its accuracy. This validation step is essential in confirming the reliability of the model's predictions. Furthermore, a dynamic scheduling tool is employed to conduct simulations, evaluating the proposed ZDM approach's impact on production. Key Performance Indicators (KPIs) are calculated during these simulations to assess the method's effectiveness in improving overall quality and efficiency [8]. SPC tools used I-MR charts, to establish parameters for PSQA using SPC equipment and consider these boundaries with those calculated using the standard deviation (σ) method. Results of 164 prostate, and 122 HN cases was found in Retrospective assessment of Point dosage PSQA. Result was found as SPC methods were better than the standard deviation-based approach in grouping process performance, which could minimize variation of protocol and guide process improvement.The research focused on assessing defects in XYZ grey fabric produced by shuttle loom 2 at a Batik manufacturing company. It utilized seven quality control tools including flowcharts, check sheets, histograms, scatter diagrams, Pareto diagrams, and fishbone diagrams. Identified defects included warp issues such as double warp and warp breaks. Analysis indicated an out-of-control process with a positive correlation between defect percentage and production numbers. Prioritization for repair was established using Pareto analysis, highlighting warp defects. The fishbone diagram identified factors contributing to defects, aiding in preventive measures to enhance product quality[9].Ramlah P, Maffud Nur Najamuddin, Serlin Serang in their review paper gave an insight that prevalent method for ongoing refinement is the application of Quality Control Circles (QCC). Their research focuses on assessing productivity improvements in the K84 Line Steering Handle following the implementation of QCC methodologies. It aims to understand the factors affecting productivity and applies QCC techniques to enhance efficiency. The research reveals promising findings, indicating that QCC-driven enhancements have substantially reduced cycle times across workstations. This reduction directly contributes to increased production output for the K84 Line Steering Handle. The utilization of QCC methods has proven remarkably effective, elevating efficiency levels from 65% to an impressive 92% and concurrently reducing manpower requirements by 3. In summary, this research emphasizes the transformative impact of QCC practices on productivity, highlighting substantial gains in output efficiency and resource optimization for the K84 Line Steering Handle. The integration of QCC-driven improvements has proven instrumental in achieving these positive outcomes[10].

3 Methodology and Application of 7 QC tools

These simple yet powerful "tools of improvement" are frequently employed as general management instruments and as "graphical problem-solving methods" across all phases of the project, from design to completion. "Everyone to understand and use the improvement tools in their work" is the industry's difficulty in manufacturing and production. Process analysis and/or process identification can be done with some of the seven tools.[4]

3.1 Cause and Effect Diagram

It shows the relationship between a problem and its possible causes.
Every potential cause that could result in the consequence is arranged in a methodical manner. First, the causes are broken down into four basic sources: MATERIAL, MACHINE, MAN, and METHOD. Subsequently, every source is further subdivided, and so on. Determining the source of the issue is beneficial.

3.2 Flow Chart

Flow charts are a visual aid that explain a process by separating it into its individual parts. Where defects are likely to occur in the system can be determined using flowcharts. Flowcharts are especially helpful in quality improvement processes to show how a process should or could ideally operate.

3.3 Pareto Diagram

The Pareto chart displays the distribution of attribute data based on categories. It is valuable for pinpointing the elements with the greatest impact on the system, enabling users to focus on these elements while disregarding the less significant ones.

3.4 Check Sheet

A check sheet is a table that is made by adding up all defects during a given period of time. It displays the flaws and the frequency of each kind of flaw throughout that time frame. Actions for improvement can be performed based on the information gathered.

3.5 Control Charts

Control charts play a vital role in identifying unusual patterns through the use of line graphs. They stand out from conventional line graphs due to the presence of control limit lines situated at the central, upper, and lower levels[5].

Control charts for variables:
The most commonly utilized variable control charts include average or X-bar charts, range or R-chart, and sigma-standard deviation charts.

Control charts for attributes:
The predominant attribute control charts consist of P-charts, NP-charts, C-charts, and U-charts.

3.6 Histogram

A visual representation illustrating the diversity within a population, the frequency data derived from measurements reveals a prominent peak centre around a specific value. The diversity in the attributes of quality is termed as distribution. The graphical depiction portraying frequency in the shape of a vertical pole is commonly known as a histogram.

3.7 Scatter Diagram

Scatter diagram is used to prove a strong relationship exists between two variables. The shape of the scatter diagram indicates the relationship between two variables.

3.8 Run chart

A run chart can be likened to a dot diagram where dots are connected by a line. The X-axis indicates the time (or date) of data collection, while the Y-axis represents the data's value. Each dot on the chart represents a single sample. Unlike Control Charts in Statistical Process Control (SPC), run charts do not have control limits (UCL and LCL). They illustrate how a process characteristic changes over time.

3.9 Box Plot

A box plot serves as a visual representation of how data is spread out, highlighting important statistics such as median, quartiles, outliers. It showcases this information using a box that shows the interquartile range (IQR) with a line marking the median across the box. Lines extend from the box to indicate the minimum and maximum values, usually at a distance of 1.5 times the IQR. This concise and informative method is highly useful for analyzing data and making comparisons.

3 Methodology

The state of inspection was carried out in wheel manufacturing industry, particularly in joining of disc and rim using submerged arc welding process. The non-destructive test of visual inspection was carried out. In this visual inspection would able to identify the weld defects of blow hole, porosity, excessive spatter, undercut and crack. These defects were recorded on daily bases of 30 days of single shift (3 hours). These collective defects were considered for analyzing using quality control tools.

4 Problem Formation

From the research conducted in the shop floor it is observed that during the welding process, various weld defects were raised such as blowholes, porosity, cracks, excessive spatter, undercuts. In this research focus is the identification of weld defects in the welding process, so it needs to be quality controlled. Seven tools are recommended for the effective implementation and evaluation of quality control systems. Utilizing these quality tools in conjunction can be advantageous quality system research. The data present in the table below pertains to weld defect occurrences in xyz Wheels Company's robotic welding machine during June 2023. The following results were obtained from the data collection check sheet are shown in Table 1. From the data, defects are often found in welding process that has been set by the company, the type of defect, respectively are:

4.1Blowholes*:* Blowholes in welding are gas pockets trapped within the weld metal, forming voids. These voids compromise the integrity of the weld.

4.2 Porosity: Porosity in welding refers to the presence of gas pockets or voids within the weld metal, weakening its structure.

4.3Excessive Spatter: Excessive spatter in welding occurs when droplets of molten metal are expelled beyond the weld area, leading to a messy finish. It is often caused by improper welding parameters, such as high voltage or incorrect wire feed speed.

4.4 Undercuts: Undercuts in welding are grooves or recessed areas along the weld toe and base metal, typically caused by excessive heat or improper welding technique. They can weaken the weld joint.

4.5 Cracks: Cracks in welding are fissures or fractures in the welded material, compromising the structural integrity of the joint. They can result from factors like high welding stress, rapid cooling, or inadequate filler material.

Table 1. Check sheet defect and inspection data

Day number	Total Inspected item	Defects					Total
		Blowholes	Porosity	Excessive Spatter	Cracks	Undercut	
1	110	9	0	17	2	3	31
2	110	10	8	10	0	2	30
3	110	6	0	3	5	4	18
4	110	8	5	10	1	3	27
5	110	6	11	5	2	1	25
6	110	8	8	8	5	2	31
7	110	10	7	8	4	3	32
8	110	15	8	13	2	3	41
9	110	8	8	5	2	2	25
10	110	6	9	10	1	0	26
11	110	11	12	9	4	3	39
12	110	15	13	8	2	1	39
13	110	12	0	7	3	2	24
14	110	9	7	4	2	3	25
15	110	10	6	6	0	4	26

16	110	9	8	5	2	1	25
17	110	9	5	4	3	0	21
18	110	13	10	0	3	2	28
19	110	10	0	6	4	3	23
20	110	9	11	8	3	0	31
21	110	10	10	3	0	0	23
22	110	14	8	2	0	0	24
23	110	22	11	5	6	5	49
24	110	7	9	5	2	1	24
25	110	12	8	4	3	3	30
26	110	16	9	5	1	7	38
27	110	20	16	6	5	4	51
28	110	8	6	3	1	2	20
29	110	9	4	8	3	0	24
30	110	10	14	1	1	0	26
31	110	12	10	3	4	2	31
Total	3410	333	241	191	76	66	907

5 Results

5.1 Histogram

From the histogram graph the table 2 shows frequency of every value in the data set occurring in a relatively objective way to determine the defects which seem to be bell shaped curve, with these graph results can be concluded as blowhole plays a major role in welding defects.

Table 2. Data for histogram

Defects types	**Total number of defects**
Blow Holes	333
Porosity	241
Excessive Spatter	191
Cracks	76
Undercut	66
Total defects	907

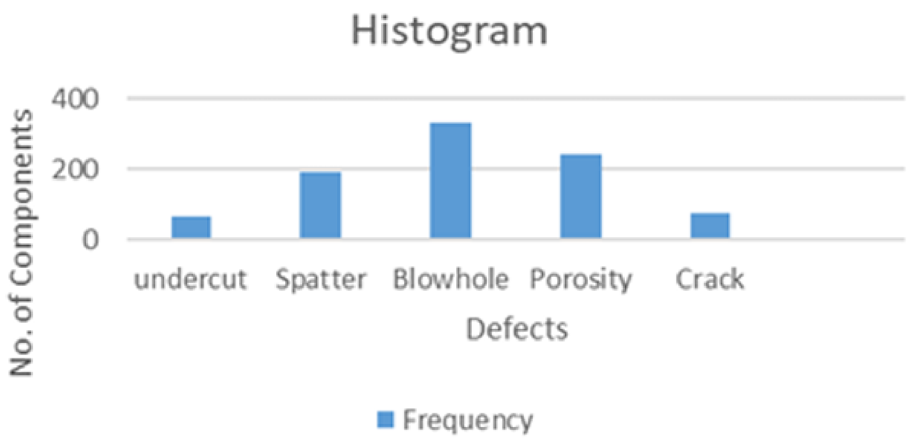

Fig.1. Histogram Chart

5.2 Pareto diagram
The pareto diagram data will be shown in Table 3.

TABLE 3. Defect type percentage

Defect Type	Total no. of Defects	Cumulative no. of defects	Cumulative percentage
Blowhole	333	333	37%
Porosity	241	574	63%
Excessive spatter	191	765	84%
Crack	76	841	93%
Undercut	66	907	100%
Total	907		

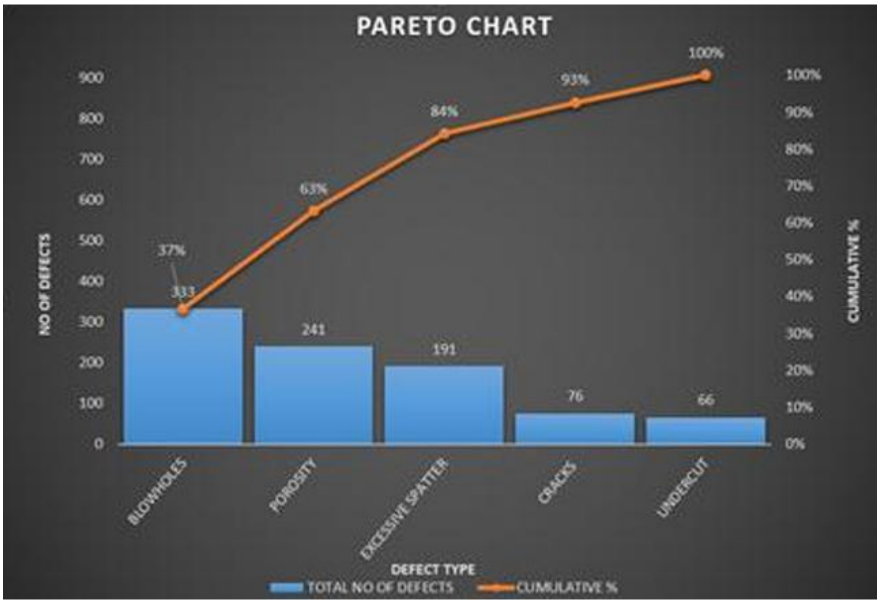

Fig. 2 Pareto Diagram

The defect chart shows that the top 20% of defects (blowholes and porosity) account for 80% of the total number of defects. This means that by focusing on reducing these two types of defects, you can achieve significant improvement.

5.3 Control Chart

The P Chart control data will be shown in Table 4.

TABLE 4. P-chart control data

Day number	Total Inspected item	Total	*p*	*CL*	LCL	UCL
1	110	31	0.281	0.265	0.139	0.392
2	110	30	0.272	0.265	0.139	0.392
3	110	18	0.163	0.265	0.139	0.392
4	110	27	0.245	0.265	0.139	0.392
5	110	25	0.227	0.265	0.139	0.392
6	110	31	0.281	0.265	0.139	0.392
7	110	32	0.29	0.265	0.139	0.392
8	110	41	0.372	0.265	0.139	0.392
9	110	25	0.227	0.265	0.139	0.392

10	110	26	0.236	0.265	0.139	0.392
11	110	39	0.354	0.265	0.139	0.392
12	110	39	0.354	0.265	0.139	0.392
13	110	24	0.218	0.265	0.139	0.392
14	110	25	0.227	0.265	0.139	0.392
15	110	26	0.236	0.265	0.139	0.392
16	110	25	0.227	0.265	0.139	0.392
17	110	21	0.19	0.265	0.139	0.392
18	110	28	0.254	0.265	0.139	0.392
19	110	23	0.209	0.265	0.139	0.392
20	110	31	0.281	0.265	0.139	0.392
21	110	23	0.209	0.265	0.139	0.392
22	110	24	0.218	0.265	0.139	0.392
23	110	49	0.445	0.265	0.139	0.392
24	110	24	0.218	0.265	0.139	0.392
25	110	30	0.272	0.265	0.139	0.392
26	110	38	0.34455	0.265	0.139	0.392
27	110	51	0.463	0.265	0.139	0.392
28	110	20	0.181	0.265	0.139	0.392
29	110	24	0.218	0.265	0.139	0.392
30	110	26	0.236	0.265	0.139	0.392
31	110	31	0.281	0.265	0.139	0.392
Total	3410	907	8.245			

The control charts, also known as statistical process control charts (SPC), are graphs utilized to analyse the evolution of a process over time. By determining the upper limit (UCL), mean value (CL), and lower limit (LCL), the control chart assesses the stability of the process. This chart incorporates two control limits, with the upper limit denoting the maximum value and the lower limit indicating the minimum value. In Figure 3 is a control process chart developed following the removal of defects from the process. The chart reveals that the process was operating out of control with variations exceeding the established tolerance levels.

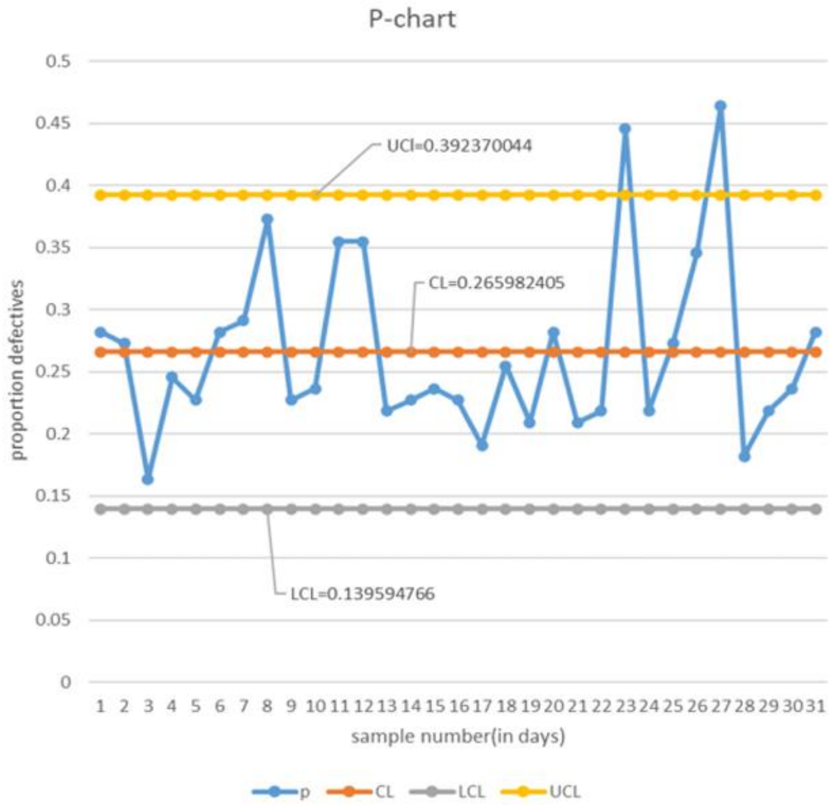

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Fig.3. P-chart

5.4 Correlation

A statistical measure that characterizes how much two variables change together is called correlation. Stated differently, it measures the correlation between two or more variables. Although correlation does not imply causation, it can be used to determine whether variables have a systematic relationship and in which direction.

Correlation Interpretation

The following interpretations apply to values of the Pearson correlation coefficient between -1 and 1:

Positive correlation ($r > 0$) denotes a tendency for both variables to rise in tandem with an increase in one. The stronger the positive correlation, the closer the correlation coefficient is equal to 1.

A negative correlation is one in which there is a tendency for one variable to decrease and vice versa ($r < 0$). The strength of the negative correlation increases with the correlation coefficient's proximity to -1.

No Correlation ($r = 0$): The two variables do not exhibit a systematic relationship. Variable changes are not predicted by changes in the other.

In statistics and data analysis, correlation is a helpful tool for understanding relationships between variables, spotting patterns, and generating predictions, among other uses. It's crucial to keep in mind nevertheless that correlation does not imply causation. A correlation between two variables does not imply that one causes the other. Since causation is a more complicated relationship, it frequently requires more investigation and experimental support to be established.

Data analysis:

The defects data were taken and the correlation was found between the defects and the correlation values has been depicted below,

Table 5. Correlation Between Defects

	Blowholes	Porosity	Excessive Spatter	Cracks
Porosity	0.409			
Excessive Spatter	-0.066	-0.255		
Cracks	0.290	-0.020	-0.019	
Undercut	0.459	-0.124	0.119	0.305

The correlation from the above data varies with respect to each defect: blowholes and porosity vary by 0.409, Excessive Spatter and Blowholes vary by -0.066 and so on.

5.5 Scatter Plots

One type of data visualization that illustrates the correlation between two continuous variables is the scatter plot. This graphical representation helps to elucidate the connection between fluctuations in one variable and those in another. The purpose of scatter plots is particularly advantageous when seeking to identify patterns, trends, groupings, or associations within datasets.

Interpreting a scatter plot:

Positive Correlation: A positive correlation is indicated if the data points generally show an upward trend as you move from left to right. This implies that the other variable tends to increase along with the increase in the first one.

Negative Correlation: A negative correlation is indicated when there is a general downward trend formed by the data points as they move from left to right. This implies that the other variable tends to decrease as the first one increases.

No Correlation: There may not be any correlation between the two variables if the data points are dispersed randomly and do not form a discernible trend.

Clustering: Data points can also be seen grouping together or forming clusters. This might point to categories or subpopulations in your data. The scatter plot on each defect with the other has been plotted with the help of Minitab software and how it varies has been shown below.

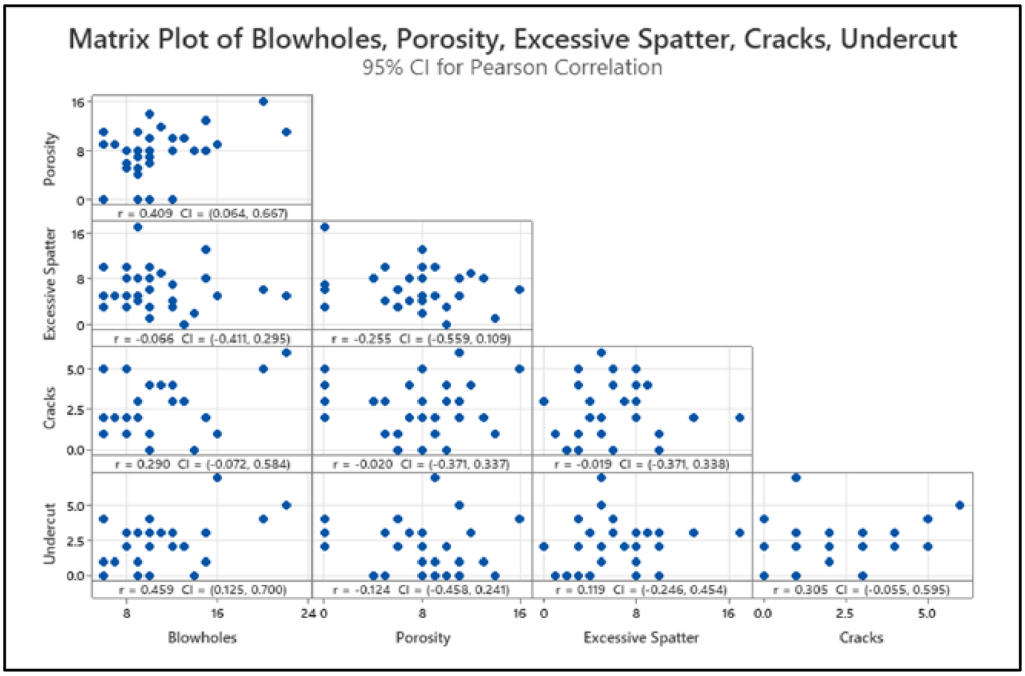

Fig. 4. Scatter Plot of Defects

The above scatter plots show us various types of scatter plots like weak positive correlation, weak negative correlation between the defects and some even depict near to zero correlation.

5.6 Run Chart

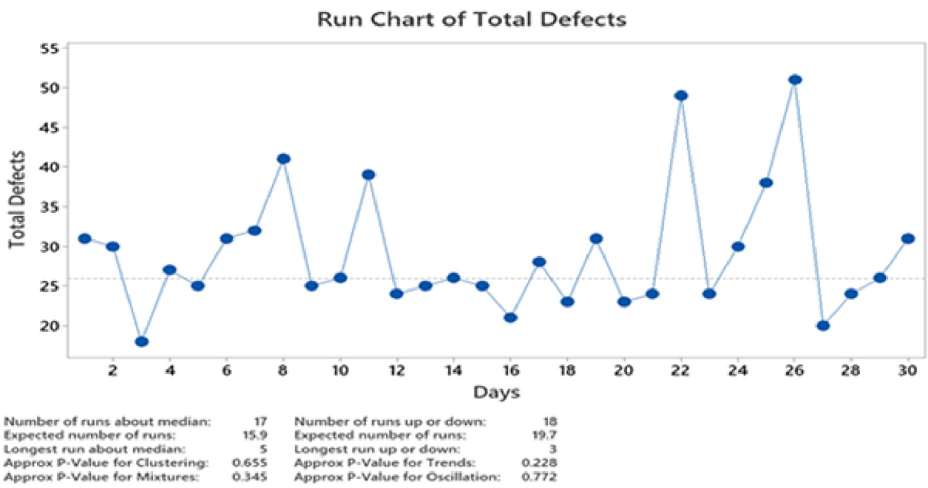

Fig. 5. Run Chart

5.7 Box Plot

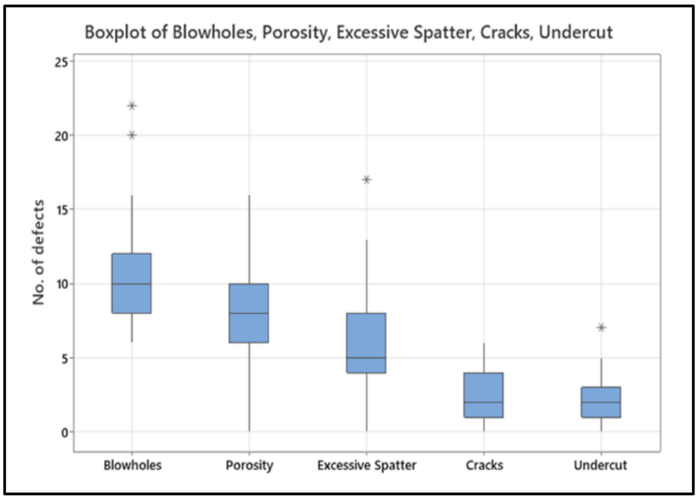

Fig. 6. Box plot

6 Conclusion

Quality control tools play a vital role in aiding production development while simultaneously ensuring customer satisfaction. This project focused on delineating the significance of seven QC tools in the wheel manufacturing process, with a primary aim to reduce weld defects in components like the Rim and Disc. Through thorough analysis, various parameters influencing end-product quality were identified, leading to the collection of precise data and the proposal of standardized welding procedures. Utilizing tools such as Histograms, Pareto charts, Control charts, and Scatter diagrams facilitated the identification of major weld defects by quality control systems, enabling the implementation of corrective measures. The key finding of this study was a notable reduction in weld defects through the prescribed methodology.

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