

ANALYSIS OF WELDING POROSITY DEFECT CONTROL USING STATISTICAL QUALITY CONTROL (SQC) METHOD IN FABRICATION COMPANIES

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Abstract

This study aims to analyze the control of welding defects in carbon steel materials at company fabrication, specifically within the Marjan Saudi Aramco project. The primary issue identified is the fluctuation in welding defect rates on pipe production, which poses a risk to offshore structural integrity. The methodology employed is Statistical Quality Control (SQC), utilizing check sheets, Pareto diagrams, p-charts, and fishbone diagrams to identify the types and root causes of defects. Data was collected from July to December 2025, covering a total welding length of 384,000 mm. The results indicate an average defect rate of 2.63%, with the most dominant defect types being porosity (35.91%) and slag inclusion (34.57%). Control chart analysis shows that despite the fluctuations, the process remains statistically in control. Through the fishbone diagram, it was determined that method and material factors are the primary causes of defects. Improvement recommendations focus on standardizing welding parameters, enhancing operator skills through training, and strengthening material cleaning procedures prior to fabrication to minimize reject rates.

Keywords: *Carbon Steel, Welding, Statistical Quality Control (SQC), Quality Control.*

INTRODUCTION

The Fabrication Company officially began operations in Batam in 1972, located in Batu Ampar, Batam. The Fabrication Company's work area includes offshore oil construction services, with five sub-areas: project management, engineering, and fabrication. It is the work location for production, material procurement, and offshore installation activities. The fabrication department produces critical products such as platforms, jackets, piping, bridges, flare booms, topsides, helidecks, and so on. To ensure these products meet company standards, they must undergo an inspection/quality control process to ensure product quality is maintained before launch (Rivaldo, 2023). The Fabrication Company is currently working on Saudi Aramco's Marjan Project, where issues arise in the construction of an offshore platform. The work required by the inspection department includes structural welding inspections (Herman, 2023).

Carbon steel is a type of steel widely used in various industrial sectors, such as manufacturing, construction, and oil and gas, due to its good mechanical properties, ease of fabrication, and relatively low cost. During the manufacturing process, this material is generally joined through welding to form a structure or component according to operational requirements (Hisyam & Jakarta, 2026). The welding process plays a crucial role in determining the quality and reliability of a product. However, this process is not free from the potential for defects caused by various factors, such as inappropriate welding parameters, inadequate operator skills, and uncontrolled work environment conditions. Some common welding defects include porosity, cracks, undercuts, and slag inclusions (Wahyudi & Ismail, 2026). The presence of these defects can reduce joint strength, compromise structural integrity, and increase the risk of failure during use (Huda & Khoiroh, 2025).

Quality control efforts are crucial in minimizing the occurrence of welding defects. One approach that can be used is Statistical Quality Control (SQC), a statistically based quality control method aimed at monitoring, controlling, and improving the quality of the production process. This method utilizes various analytical tools, such as control charts, histograms, and Pareto diagrams, to identify process variations and determine the root causes of defects (Darmawan, Rizqi, 2022). The application of SQC in the welding process is expected to provide accurate information regarding the level of process stability and defect patterns, allowing for appropriate and targeted corrective actions (Devindra et al., 2025). This, in turn, improves the quality of the weld and minimizes the defect rate. The defects frequently encountered in the pipe joining process in the welding department are:

a. Undercuts in welding



Figure 1. Undercut in Welding

Undercut is a defect in the weld edge that occurs due to high amperage settings on the welding machine. Undercut is also very dangerous because it can cause cracks in the vibrating material and reduce the weld's resistance (Hamdani, Fakhriz, 2019).

b. Slag Inclusion



Figure 2. Slag Inclusion

Slag inclusion is a welding defect in which non-metallic material (slag) is trapped within the weld metal or between weld layers, causing internal discontinuities and reducing the joint strength (Tanaka et al., 2024).

c. Porosity



Figure 3. Porosity

Porosity is a welding defect characterized by the formation of small cavities (pores) within or on the surface of the weld metal caused by gas trapping during the molten metal solidification process (Hakimian et al., 2024).

Based on this description, this study aims to analyze the control of welding defects in carbon steel using the Statistical Quality Control (SQC) method and to provide recommendations for improvements to enhance the quality of the welding process. The defect levels in the pipe welding process are shown in the table below:

Table 1. Pipe Welding Defects

No	Bulan	Unit	length (mm)	Undercut (mm)	Porosity (mm)	Slag (mm)	Total Reject	Present reject	Total Accept	Present Accept
1	Juli	10	80.000	500	350	750	1.600	3.33%	78.400	98.00%
2	Agustus	6	48.000	475	1000	350	1.825	2.28%	46.175	96.20%
3	September	8	64.000	890	670	700	2.260	4.04%	61.740	96.47%
4	Oktober	8	64.000	500	300	250	1.050	2.19%	62.950	98.36%
5	November	6	48.000	170	500	600	1.270	1.59%	46.730	97.35%
6	Desember	10	80.000	440	800	835	2.075	3.71%	77.925	97.41%
Total		48	384.000	2.975	3.620	3.485	10.080		373.920	

The data in the table shows defects occurring in the carbon steel pipe welding process from July to December. The total length of the observed pipe joints was 384,000 mm, with a total of 10,080 mm of defects (rejects). Defects occurring in the welding process comprised three main types: undercut, porosity, and slag inclusion. Based on the data obtained, the defect with the highest number was porosity at 3,620 mm, followed by slag inclusion at 3,485 mm, and undercut at 2,975 mm. This indicates that the dominant defects were related to gas trapping and welding process cleanliness (M. W. Hidayat & Negoro, 2024).

The defect tolerance level set in this study was 2.5%. Based on the calculations, several months exceeded this tolerance limit: July (3.33%), September (4.04%), October (2.19% approaching the limit), and December (3.71%). Meanwhile, the month with the lowest defect rate was November, with a percentage of 1.59%, indicating the most stable welding process conditions. The highest defect rate occurred in September, with a total of 2,260 mm and a percentage of 4.04%. This indicates uncontrollable welding processes during that period, possibly caused by welding parameters, operator skills, or work environment conditions (Bakhtiar et al., 2013).

Overall, the data shows that the welding process still experiences fluctuations in defect rates and is not yet fully under control. Therefore, the application of Statistical Quality Control (SQC) methods is necessary to analyze process stability, identify the root causes of defects, and determine corrective actions to reduce the defect rate within the established tolerance limits. Therefore, the author conducted this research, entitled "Analysis of Welding Defect Control in Carbon Steel Material Using Statistical Quality Control (SQC) Methods."

LITERATURE REVIEW

Carbon Steel Material

Carbon steel is a type of steel containing carbon as the main element, influencing the mechanical properties and microstructure of the material (Budiono et al., 2026). Carbon steel is used in the manufacturing and oil and gas industries due to its good strength, malleability, and relatively low production costs. However, carbon steel has the disadvantage of relatively low corrosion resistance, making the quality of the fabrication process, particularly welding, crucial to maintaining material integrity (Faiq et al., 2025).

Welding Process

Welding is the process of joining two metal materials by heating them to their melting point, with or without additives, to produce a permanent joint. The quality of the weld is greatly influenced by process parameters such as current, voltage, welding speed, and operator skill. In practice, mismatches in these parameters can lead to defects in the welded joint, which can reduce the strength and reliability of the structure (Paul, 2023).

Welding Defects

Welding defects are imperfections that occur in welded joints that can reduce the quality and strength of the material. Some common types of defects include (Wahyudi & Ismail, 2026):

a. Undercut

An undercut is a defect in the form of a groove or depression on the edge of the base metal that is not filled by the weld metal, causing thinning in the joint area and increasing stress concentrations (Mei et al., 2024).

b. Porosity

Porosity is a defect in the form of small cavities formed due to gas trapping during the weld metal solidification process, which can reduce the strength and density of the joint (R. Puji & J Supono, 2020).

c. Slag Inclusion

Slag inclusion is a defect in which non-metallic material (slag) is trapped within the weld metal, causing internal discontinuities and reducing the mechanical strength of the joint (Faiq et al., 2025).

These defects can be caused by various factors such as inappropriate welding parameters, poor material cleanliness, and inappropriate welding techniques.

Quality Control in Welding

Quality control is a systematic effort to ensure that products meet established standards. In the welding process, quality control aims to minimize defects and maintain consistent production results (Berbasis et al., 2024). Implementing quality control is crucial for increasing production efficiency and reducing costs resulting from welding defects (Darmawan, Rizqi, 2022).

Statistical Quality Control (SQC)

The Statistical Quality Control (SQC) method is a quality control technique that uses a statistical approach to monitor and control variations in the production process. SQC allows for early identification of process deviations so that corrective actions can be taken before a large number of defective products are produced (Agboola & Ikubanni, 2017). Some common tools used in SQC include:

- a. Check Sheet
- b. Pareto Diagram
- c. Control Chart (P-Chart)
- d. Cause and Effect Diagram (Fishbone Diagram)

Relationship between Welding Defects and Quality Control

Welding defects are directly related to the effectiveness of quality control in a production process. A high defect rate indicates that the process is not yet in statistical control (Khoiri & Aryani, 2025). Therefore, the application of SQC methods is essential to analyze defect patterns, identify root causes, and determine appropriate corrective actions.

METHOD

Data Collection

This research, conducted by the author, began in July 2025 and lasted until December 2025. The research proposal and analysis were developed and implemented through two stages of analysis: primary and secondary data. Primary data was collected directly by individuals/organizations from the research subjects for the purposes of the study, including interviews and observations in the analysis of defect control in oil and gas pipeline welding (S. T. Hidayat et al., 2024). Secondary data was obtained through production data, defect and ACC and reject pipe data, as well as journals and previous research literature related to defect control in oil and gas pipeline welding (Herman, 2023).

Data collection methods are techniques or methods employed by researchers to collect data (Yasmin et al., 2025). Data collection is conducted to obtain the information needed to achieve the research objectives required to analyze defect control in pipe welding in fabrication companies (Susilo et al., 2025).

Data Processing

Based on the data collection above, to make this research more structured, the author designed a data processing structure for the analysis of welding defect control in carbon steel using the Statistical Quality Control (SQC) method (Pandapotan & Mulyadi, 2024). The author used several stages in this research. The following are the stages in data processing:

- a. Check Sheet
- b. Pareto Diagram
- c. Control Chart (P)
- d. Fishbone Diagram

Problem-Solving Framework

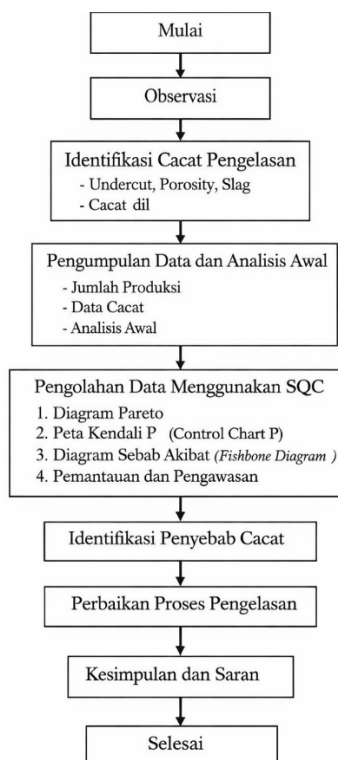


Figure 4. Problem Solving Framework

RESULTS AND DISCUSSION

Data Processing

1. Checksheet

Table 2. Total Pipe Welding Defects

No	Bulan	Jumlah (Unit)	Total Panjang pipa (mm)	Jumlah Cacat Produk	Keterangan cacat dan panjang (mm)	Total Panjang cacat (mm)
1	Juli	10	80.000	6	Porosity : 350 Undercut : 500 Slag : 750	1.600
2	Agustus	6	48.000	3	Porosity : 1.000 Undercut : 475 Slag : 350	1.825
3	September	8	64.000	5	Porosity : 670 Undercut : 890 Slag : 700	2.260
4	Oktober	8	64.000	3	Porosity : 300 Undercut : 500 Slag : 250	1.050
5	November	6	48.000	4	Porosity : 500 Undercut : 170 Slag : 600	1.270
6	Desember	10	80.000	3	Porosity : 800 Undercut : 440 Slag : 835	2.075
Total/Rata-Rata		48	384.000	24		10.080

During the observation period, total production was recorded at 48 units with a total machining length of 384,000 mm. Of this total production, 24 defective units were found with a total defect length of 10,080 mm. When compared to the total production length, the percentage of defect length to total production length is as follows:

$$\frac{10.080}{384.000} \times 100\% = 2.63\% \dots\dots\dots(1)$$

The calculation results show that the defect rate based on defect length was 2.63%. This value indicates that there are still quality deviations in the welding process, although generally it is close to the established tolerance limits. Overall, the most dominant type of defect during the study period was porosity, followed by slag inclusion and undercut. The dominance of porosity defects indicates problems in the welding process related to gas trapping

during the weld metal solidification process. Meanwhile, slag inclusion defects indicate suboptimal slag cleaning or inappropriate welding techniques. Undercut defects indicate mismatched welding parameters, such as excessive current or inappropriate welding speed.

Based on the analysis, the defect rate of 2.63% is still quite significant and has the potential to cause losses, both in terms of rework costs and production delays. Therefore, continuous improvement efforts are needed through enhanced welding process control, work parameter adjustments, and operator skill enhancement.

Furthermore, the application of quality control methods such as Statistical Quality Control (SQC) using tools like Pareto diagrams, fishbone diagrams, control charts, and checksheets can help systematically identify the root causes of defects. This allows for more effective and targeted corrective actions to reduce the defect rate in the welding process.

2. Pareto Diagram

A Pareto diagram is a tool for comparing various categories of events arranged according to their size to determine the priority of the categories to be analyzed (Ramadayanti & Suryadi, 2024). This can be seen in the table below:

Table 3. Pareto Diagram Percentage

No.	Jenis Defect	Frekuensi Unit (joint)	Persentase	Persentase Kumulatif
1	Porosity	3.620	35.91%	29.51%
2	Slag Inclusion	3.485	34.57%	64.08%
3	Undercut	2.975	29.51%	100%
Jumlah		10.080	100%	

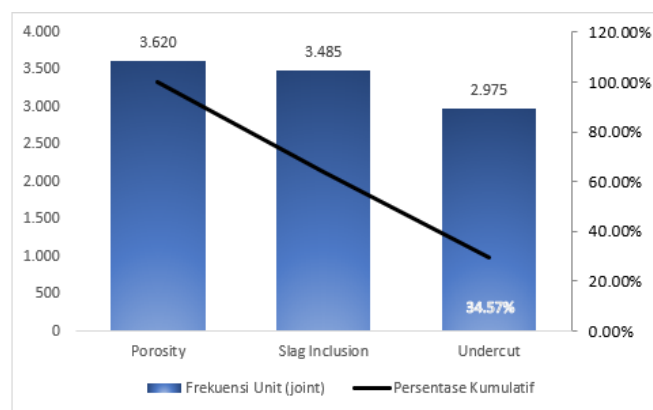


Figure 5. Pareto Diagram

Based on the Pareto diagrams presented in Table 3 and Figure 4, it is clear that three main types of defects occurred during the production process: undercut, porosity, and slag inclusion. The total length of defects was 10,080 mm, with each defect contributing 3,620 mm (35.91%), 3,485 mm (34.57%), and 2,975 mm (29.51%) to the total: porosity, followed by slag inclusion, and undercut with the smallest contribution.

Cumulatively, porosity contributed an initial 35.91%, and when combined with slag inclusion, it reached 65.42% of the total defects. This indicates that more than half of the quality problems were caused by these two types of defects. Therefore, in accordance with the Pareto principle, the primary focus of improvement should be directed at controlling porosity and slag inclusion defects, as these have the most significant impact on welding quality.

Therefore, based on the Pareto diagram analysis, it can be concluded that efforts to improve welding quality should focus on controlling porosity and slag inclusion defects. The application of quality control methods such as Statistical Quality Control (SQC) is expected to help identify the root causes of defects more systematically and determine effective corrective actions to reduce the overall defect rate.

3. P-Control Chart

After constructing the Pareto diagram, the next step is to create a control chart (p-chart), which is useful for determining whether quality control in the company is running well. As previously explained, the first step in creating a control chart is as follows:

- Calculate the P-Chart for July - December 2025. Calculate the central line (CL).

Where:

$\sum np$: Total number of damaged items

$\sum n$: Total number inspected

$$\sum np : 10,080$$

$$\sum n : 384,000$$

$$CL = \frac{\sum np}{n} = \frac{10080}{384000} = 0.026$$

- b. Calculating the control limit for supervision carried out by setting the upper control limit (UCL), for example the calculation for August:

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

Where:

P = Average welding defects

K = Confidence level

n = Total Group / Sample

In this case, for a 99% confidence level, the K value is 3. From the formula above, the upper control limit can be obtained as follows:

$$UCL = 0.026 + 3 \left(\sqrt{\frac{0.026 (3 + 0.026)}{80000}} \right) = 0.03$$

- c. Calculate the control limits for supervision carried out by setting the lower control limit (UCL), for example the calculation for August:

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

Where:

P = Average welding defects

K = Confidence level

n = Total Group / Sample

In this case, for a 99% confidence level, the K value is 3. From the formula above, the upper control limit can be obtained as follows:

$$LCL = 0.026 - 3 \left(\sqrt{\frac{0.026 (3 - 0.026)}{80000}} \right) = -0.22$$

- d. Creating a P-Chart

Table 5. Overall CL, UCL, and LCL Defect Values

Month	Pipe Welding Length	Defect Length	Proportion	CL	UCL	LCL
Jul	80,000	1,600	0.02	0.026	0.03	-0.022
Aug	48,000	1,825	0.04	0.026	—	—
Sep	64,000	2,260	0.03	0.026	—	—
Oct	64,000	1,050	0.035	0.026	—	—
Nov	48,000	1,270	0.026	0.026	—	—
Dec	80,000	2,075	0.025	0.026	—	—
Total	384,000	10,080	0.176	—	—	—

Based on the table, the total length of pipe welding during the observation period was 384,000 mm, with a total defect length of 10,080 mm. The proportion of total defects was 0.176, obtained by comparing the total defects to the total cumulative production.

A P-chart is created to illustrate a process and indicate when a process is out of control. The process will then be investigated to determine the cause of the out-of-control condition, which will then be followed by root cause analysis. The following table and graph results for July - December 2025:

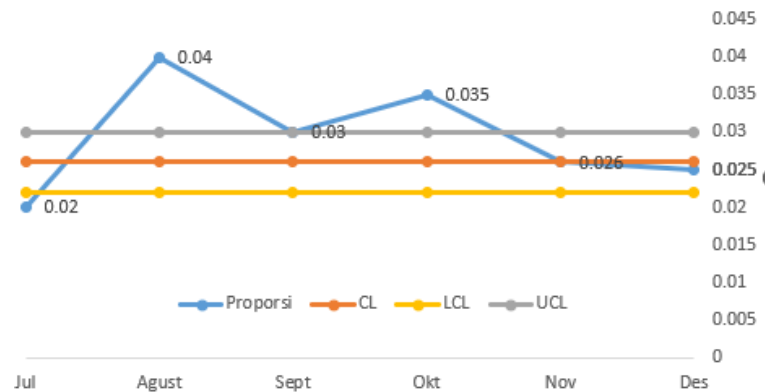


Figure 5. P-Chart

Based on the control chart (p-chart) for the carbon steel pipe welding process, the defect proportion fluctuated between July and December. The highest defect proportion occurred in August at 0.04, then decreased in September to 0.03, and then increased again in October to 0.035. Furthermore, in November and December, the defect proportion decreased to 0.026 and approached 0.025, respectively.

Based on the control limits, namely the Upper Control Limit (UCL), Central Line (CL), and Lower Control Limit (LCL), all defect proportion values remained within the established control limits. This indicates that the welding process is statistically in control. However, the fluctuations in the defect proportion values during each period indicate that the process is not yet fully stable and that variations still require attention.

4. Cause-and-Effect Diagram (Fishbone Diagram)

A cause-and-effect diagram shows the relationship between the problem encountered and its possible causes and influencing factors. The most important thing to do and track is to find the root cause of the welding defect. For more details, see the following cause-and-effect diagram:

- Workers (People), namely workers directly involved in the production process.
- Raw Materials (Materials), namely the components used to produce a finished product.
- Machines (Machine), namely the tools or machines used.
- Work Procedures (Manual), namely work standards based on applicable regulations.
- Methods (Methods), namely the work methods that must be followed in the production process.
- Environment (Environment), namely the conditions surrounding the production site that directly or indirectly influence the production process.

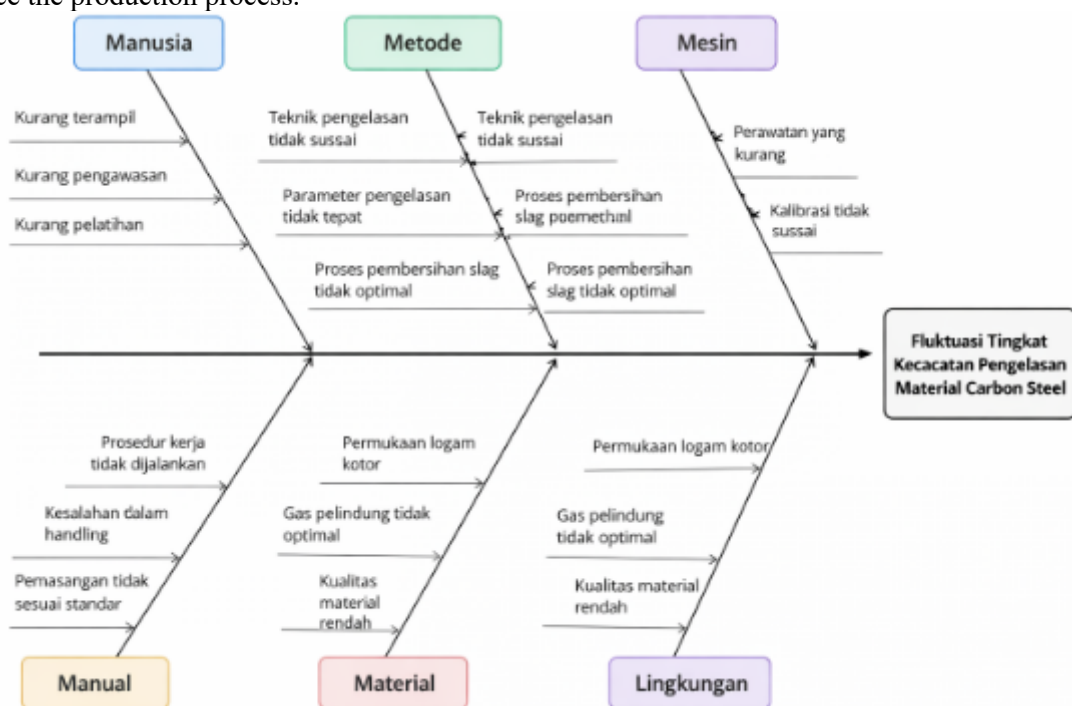


Figure 6. Fishbone Diagram

The following is an evaluation of the fishbone diagram:

- a) Human factors relate to the operator's ability to perform the welding process. Lack of skills, inadequate training, and weak supervision can lead to errors in welding techniques, leading to defects such as porosity, slag inclusion, and undercuts. Inexperienced operators tend to be unable to consistently control welding parameters.
- b) Method factors include the welding techniques and procedures used. Inconsistencies in work methods with operational standards, such as incorrect current, voltage, welding speed, and electrode angle, can result in suboptimal welding results. Furthermore, inadequate slag cleaning can also potentially lead to slag inclusion defects.
- c) Machine factors relate to the condition and performance of welding equipment. A poorly maintained welding machine, not regularly calibrated, or experiencing decreased performance can cause unstable electrical currents, affecting the quality of the weld and increasing the risk of defects.
- d) Material factors relate to the condition of the materials used. Dirty material surfaces, rust, oil, or other contamination can cause gas trapping during the welding process, resulting in porosity defects. Furthermore, substandard material quality can also reduce the quality of welded joints.
- e) Manual factors (work procedures) include the implementation of standard operating procedures in the field. Poorly executed work procedures, errors in material handling, and non-standard installation can cause physical defects in the weld. This demonstrates the importance of consistently implementing SOPs.
- f) Environmental factors include conditions in the work area, such as temperature, humidity, and cleanliness. An uncontrolled work environment, such as high humidity, dust, or poor ventilation, can affect the stability of the welding arc and the quality of the weld.

Analysis Results and Discussion

Based on the overall analysis, it can be seen that the welding defect rate of 2.63% still indicates imperfections in the production process. Although the process is statistically within control limits, fluctuations indicate that the process is not consistently stable. The dominance of porosity defects indicates problems with shielding gas control and material cleanliness, while the high level of slag inclusions indicates suboptimal slag cleaning processes and welding techniques. This is supported by the results of the fishbone analysis, which indicate that method and material factors are the primary causes of defects.

Therefore, the continuous application of Statistical Quality Control (SQC) methods is necessary to monitor and control the welding process. In addition, improvement efforts are needed, such as:

- a. improving operator skills through training
- b. controlling welding parameters according to standards
- c. improving material cleanliness before welding
- d. regular machine maintenance and calibration

Weld defect control also requires a combination of technical controls, human resources, and an integrated quality management system. One of the key requirements is the standardization of welding parameters, such as current, voltage, welding speed, and electrode angle. Inappropriate parameters can cause defects such as porosity, slag inclusion, and undercuts, so settings must adhere to established procedures (WPS – Welding Procedure Specification). Furthermore, operator skill and competence are crucial factors. Untrained operators tend to produce high variations in weld quality. Therefore, regular training, welder certification, and direct supervision during the welding process are required to ensure work is performed according to standards. Another factor is material condition and surface cleanliness. Dirty, rusty, or oil-contaminated material can cause defects, especially porosity. Therefore, cleaning before welding is a crucial step in quality control.

Regarding equipment, welding machines must be kept in good condition through regular maintenance and calibration. Unstable machines can cause electrical current fluctuations, which directly impact weld quality. Furthermore, the work environment also affects weld quality. Factors such as humidity, temperature, and airflow can affect arc stability and the metal solidification process. An uncontrolled environment can increase the potential for defects. From a managerial perspective, implementing quality control methods such as Statistical Quality Control (SQC) to statistically monitor the process is essential. The use of tools such as check sheets, Pareto charts, control charts, and fishbone diagrams can help systematically identify defect patterns and their root causes. This requires a continuous evaluation and improvement system, where each production result is analyzed to identify deviations and take corrective action. This aims to consistently reduce defect rates and improve product quality.

CONCLUSION

Based on the research results on the analysis of welding defect control in carbon steel using the Statistical Quality Control (SQC) method, the following conclusions can be drawn:

1. The defect rate in the welding process was 2.63%, based on the ratio of the total defect length to the total production length. This value indicates that the welding process still experiences quality deviations and has not yet fully met stable process conditions.
2. The most dominant types of defects, based on the Pareto diagram analysis, were porosity and slag inclusion, with a cumulative contribution of 65.42% of the total defects. This indicates that the majority of quality problems focused on these two types of defects.
3. Based on the control chart (p-chart) analysis, the welding process was statistically within control limits (in control), but there were fluctuations in the proportion of defects, indicating that the process was not fully stable and was still influenced by variations in certain causes.
4. The results of the fishbone diagram analysis indicated that the primary causes of defects stem from method and material factors, supported by other factors such as human factors, machines, work procedures, and the environment. These factors contribute to the emergence of porosity and slag inclusion defects.
5. Efforts to control welding defects can be achieved through the systematic implementation of quality control, including improving operator skills, controlling welding parameters, improving work procedures, and maintaining material and work environment conditions. Continuous application of SQC methods can help reduce defect rates and improve welding quality.

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