Analysis of Pipe Welding Quality Control Using The Seven Tools Method In The Manufacturing Industry

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Abstract.
Weld quality plays an important role in ensuring the reliability and safety of pipe products in the manufacturing industry. Welding defects may increase production costs, require rework, and reduce operational efficiency. This study aims to identify welding defects, determine the dominant defect types, analyze their root causes, and propose quality improvement strategies using the Seven Quality Control (Seven QC) Tools. The research applied Check Sheet, Histogram, Pareto Diagram, Fishbone Diagram, Scatter Diagram, Flow Chart, and P-Control Chart (P-Chart). Data were collected from January to June 2026, consisting of 3,090 welded joints with 209 defective welds. The results showed an overall defect rate of 6.76%, with porosity as the most dominant defect (38.28%), followed by crack (25.36%) and undercut (17.70%). Pareto analysis indicated that these three defects contributed 81.34% of the total defects. The P-Chart confirmed that the welding process remained statistically under control, while the Fishbone Diagram identified man, machine, method, material, measurement, and environment as the main causes of defects. The proposed improvements include operator training, strict implementation of the Welding Procedure Specification (WPS), preventive maintenance, improved material control, and enhanced inspection procedures to reduce welding defects and improve product quality.
Keywords: *Quality Control, Pipe Welding, Seven Quality Control Tools, Pareto Diagram, Fishbone Diagram and P-Control Chart (P-Chart).*

I. INTRODUCTION

The manufacturing industry plays a significant role in supporting economic growth through production activities that generate various high quality components and products. In facing increasingly competitive global markets, manufacturing companies are required to produce products that comply with quality standards, maintain low defect rates, and achieve efficient production processes (Dahda, 2023). One of the critical processes that determines product quality in the manufacturing industry is the welding process, particularly in pipe-based products. The quality of pipe welding is a crucial factor because it directly affects mechanical strength, pressure resistance, product service life, and operational safety (Al-bar *et al.*, 2026).

Pipe welding is a joining process that combines two or more metal materials by applying heat to create a permanent metallurgical bond. Although welding technology has developed significantly, this process still has the potential to produce various types of weld defects, including porosity, cracks, undercut, lack of fusion, slag inclusion, and incomplete penetration. The occurrence of these defects may reduce product quality, increase production costs due to rework and scrap, cause delays in product delivery, and increase the risk of structural failure during operation (Epyt *et al.*, 2024). Therefore, companies need to implement an effective quality control system to minimize defect occurrence and maintain production reliability.

Quality control refers to a series of systematic activities designed to ensure that products meet predetermined specifications and quality requirements. Quality control is not limited to final product inspection but also involves controlling the production process from the early stages to identify and prevent deviations before they become major problems (Tsabit *et al.*, 2022). One widely applied approach in quality improvement is the Seven Quality Control Tools (Seven QC Tools). This method consists of seven fundamental quality management tools, namely check sheets, histograms, Pareto diagrams, cause and effect diagrams (fishbone diagrams), control charts, scatter diagrams, and flow charts. These tools assist organizations in collecting quality data, identifying dominant defect types, analyzing process variations, determining root causes, and developing systematic improvement strategies (Mardiansyah *et al.*, 2025).

The implementation of Seven Quality Control Tools in pipe welding processes provides significant benefits because it enables both quantitative and visual analysis of quality performance. A check sheet is used to record the frequency and occurrence of defects during inspection activities. A histogram helps analyze defect data distribution, while a Pareto diagram identifies the most critical defect types based on the 80/20 principle. A fishbone diagram is applied to investigate the root causes of defects by examining factors such as manpower, machinery, materials, methods, environment, and measurement systems. Meanwhile, a control chart is utilized to evaluate whether the welding process remains statistically stable and within acceptable control limits (Fikri *et al.*, 2023). Through the integration of these tools, companies can establish improvement priorities based on objective data, allowing quality enhancement programs to be implemented more effectively.

PT XYZ Manufacturing is a company engaged in steel pipe fabrication for the oil and gas industry. One of the main production processes involves welding operations using Shielded Metal Arc Welding (SMAW) and Gas Tungsten Arc Welding (GTAW) methods. During the production process, several products were identified as failing to meet quality requirements, resulting in repair welding activities and product rejection. Therefore, the company aims to identify the dominant types of welding defects and determine their primary causes through the application of Seven Quality Control Tools (Haloho *et al.*, 2023). This research was conducted during the period of January to June 2026. The following table presents the types of defects identified during the pipe welding process:

Table 1. Six-Month Production Data

No.	Month	Total Welding Joints	Defective Products	Defect Percentage (%)
1	January	480	28	5.83
2	February	500	31	6.20
3	March	520	36	6.92
4	April	510	33	6.47
5	May	530	39	7.36
6	June	550	42	7.64
	Total	**3,090**	**209**	**6.76**

Results of 2026 researcher data processing

Based on the data presented in Table 1, the average defect rate during the six-month production period was 6.76%. The lowest defect rate occurred in January at 5.83%, while the highest defect rate was recorded in June at 7.64%. The increasing defect percentage from January to June indicates that higher production volumes tend to be accompanied by an increase in defective products. This condition may be influenced by several factors, including increased operator workload, variations in welding parameters, declining welding machine performance, inconsistent material quality, and less effective inspection activities during the production process.

Table 2. Welding Defect Classification Data

No.	Defect Type	January	February	March	April	May	June	Total
1	Porosity	10	12	14	13	15	16	80
2	Crack	7	8	9	8	10	11	53
3	Undercut	5	5	6	6	7	8	37
4	Lack of Fusion	4	4	5	4	5	5	27
5	Slag Inclusion	2	2	2	2	2	2	12
	Total	**28**	**31**	**36**	**33**	**39**	**42**	**209**

Results of 2026 researcher data processing

Based on the quality inspection results of the pipe welding process during the period of January to June 2026, five major types of welding defects were identified, namely porosity, crack, undercut, lack of fusion, and slag inclusion. During the six-month observation period, a total of 209 defects were detected from 3,090 inspected welding joints. The most frequently occurring defect was porosity with 80 occurrences, followed by crack with 53 occurrences, undercut with 37 occurrences, lack of fusion with 27 occurrences, and slag inclusion with 12 occurrences. These findings indicate that porosity represents the dominant quality issue in the welding process and requires priority attention for improvement.

The occurrence of porosity increased from 10 cases in January to 16 cases in June, while crack defects increased from 7 to 11 cases. Similarly, undercut defects increased from 5 to 8 cases during the observation period. Meanwhile, lack of fusion defects remained relatively stable, ranging from 4 to 5 cases, whereas slag inclusion showed the lowest and most consistent occurrence rate, with only 2 cases each month. This pattern suggests that increased production intensity may contribute to a higher number of welding defects during manufacturing activities (Aziz *et al.*, 2023).

Furthermore, the defect contribution analysis showed that porosity accounted for 38.28% of the total defects, followed by crack at 25.36%, undercut at 17.70%, lack of fusion at 12.92%, and slag inclusion at 5.74%. The combined contribution of the three dominant defects, namely porosity, crack, and undercut, reached 81.34% of all recorded defects. This result demonstrates that most quality problems originated from these three defect categories, making them the primary targets for quality improvement efforts. In general, the high occurrence of porosity, crack, and undercut defects may be associated with several factors, including improper welding parameter settings, poor electrode or material conditions, insufficient operator skills, and inadequate implementation of welding procedures based on the Welding Procedure Specification (WPS) (Rodjak & Khoiroh, 2024). Therefore, further analysis using the Pareto Diagram, Fishbone Diagram, and Control Chart (P-Chart) is required to determine the main causes of defects, evaluate welding process stability, and develop appropriate corrective actions to reduce defect rates and improve pipe welding quality (Matondang *et al.*, 2024).

Based on these considerations, this study aims to analyze the quality control of pipe welding processes using the Seven Quality Control Tools method in a manufacturing industry. The research was conducted by collecting welding inspection data, identifying defect types, analyzing defect frequency and distribution patterns, determining priority defects for improvement, and investigating the root causes of quality problems through quality control analysis tools.

II. METHODS

This study employed a quantitative descriptive research approach to analyze the quality control performance of the pipe welding process in a manufacturing industry. The quantitative approach was selected because the research utilized numerical data related to production quantities, welding joint inspections, and defect occurrences, while the descriptive approach was applied to identify defect characteristics, analyze defect distribution patterns, and determine improvement priorities. Quantitative quality analysis is commonly used in manufacturing industries because it provides objective information regarding process performance and supports data-driven decision-making for continuous improvement (Antony *et al.*, 2023).

The research was conducted at PT XYZ Manufacturing, a company engaged in steel pipe fabrication for the oil and gas industry. The research object focused on the pipe welding process because welding quality directly influences product reliability, mechanical strength, pressure resistance, and operational safety. Welding defects may lead to product rejection, repair activities, increased production costs, and reduced manufacturing efficiency (Dagmar *et al.*, 2023). The data collection process was conducted through direct observation and documentation of welding inspection records during the period of January to June 2026. Field observation was performed by examining welding activities, operator performance, equipment conditions, production procedures, and quality inspection practices. Direct observation was conducted to obtain actual information regarding production conditions and to identify factors that potentially contributed to welding defects. Observation-based data collection is important in manufacturing research because it allows researchers to connect statistical findings with real production conditions (Jannaah *et al.*, 2025).

The primary data used in this study consisted of welding inspection results involving 3,090 welding joints, with 209 defective welding joints identified during the six-month observation period. The collected data included the number of inspected welding joints, defect frequency, defect classification, and defect percentage. The identified welding defects consisted of porosity, crack, undercut, lack of fusion, and slag inclusion. These defect categories were analyzed to determine the dominant problems affecting welding quality performance.

The data analysis was conducted using the Seven Quality Control Tools (Seven QC Tools) approach. This method was selected because Seven QC Tools provides a structured framework for identifying quality problems, analyzing defect patterns, determining root causes, and developing corrective actions. The application of quality tools such as check sheets, Pareto diagrams, control charts, and fishbone diagrams has been widely applied in manufacturing industries to improve process stability and reduce product defects (Antony *et al.*, 2023).

The first stage of analysis used a Check Sheet to collect and classify welding defect data systematically. The check sheet was used to record the frequency and type of defects occurring during the inspection period. This tool provides a structured database that supports further statistical analysis and helps identify recurring quality problems (Barsalou, 2023). The second stage involved the use of a Histogram to evaluate the distribution pattern of welding defects. Histogram analysis was applied to observe variations in defect occurrence and to understand the characteristics of quality problems within the welding process. Statistical visualization through histograms assists researchers in identifying abnormal patterns and evaluating process performance (McDermott *et al.*, 2023).

The third stage applied a Pareto Diagram to determine the dominant welding defects requiring priority improvement. Pareto analysis was performed by ranking defect types based on frequency and calculating their cumulative contribution. This approach follows the Pareto principle, where a limited number of defect categories generally contribute significantly to overall quality problems. Previous studies have shown that Pareto analysis is effective in determining critical defect sources and establishing improvement priorities in manufacturing processes (Dagmar *et al.*, 2023).

The fourth stage used a P-Control Chart (P-Chart) to evaluate whether the welding process was statistically controlled. The P-Chart was selected because the research data represented attribute quality characteristics, where products were categorized as defective or non-defective based on inspection results. The analysis involved calculating the defect proportion, central line (CL), upper control limit (UCL), and lower control limit (LCL). Control charts are widely used in manufacturing quality systems to monitor process stability and detect variations that may require corrective action (Antony *et al.*, 2023).

The final stage applied a Fishbone Diagram (Cause-and-Effect Diagram) to identify the root causes of welding defects. The analysis was conducted using the six main factors of the 6M approach, namely Man, Machine, Material, Method, Measurement, and Environment. Fishbone analysis is effective for identifying relationships between quality problems and their possible causes, particularly in manufacturing processes involving complex interactions between human factors, equipment, materials, and production methods (Jannaah *et al.*, 2025).

The research procedure was conducted through several sequential stages, including problem identification, literature review, field observation, data collection, data processing using Seven QC Tools, defect analysis, root cause identification, and formulation of quality improvement recommendations. This systematic research framework was designed to provide comprehensive analysis of welding defects and develop practical recommendations for improving pipe welding quality performance in manufacturing industries.

III. RESULT AND DISCUSSION

Data Processing

As the initial stage of the research, researchers conducted direct observations in the production area to obtain a realistic picture of the pipe welding process. Observations included observing the welding process stages, work environment conditions, the implementation of operational procedures, and inspection activities carried out by production and quality control personnel. These field observations aimed to obtain primary data that would serve as a basis for identifying various factors that could potentially cause welding defects.

Fig. 1. Field Observations

Based on the observation results shown in Figure 2, it is clear that the work process involved coordination between operators, supervisors, and inspection officers to ensure each stage of the work was carried out in accordance with established procedures. The researcher also conducted direct observations of material conditions, work methods, equipment use, and worker compliance with operational standards. The researcher's direct involvement in the observation process allowed for more comprehensive information regarding actual conditions in the field, thus enhancing the validity of the collected data.

The observations indicated that although the welding process was carried out according to company procedures, several potential causes of non-conformity in the quality of the weld results remained. These factors included material readiness prior to welding, welding parameter settings, equipment condition, operator competence, and the influence of the work environment. These initial findings were then analyzed using the Seven Tools method to identify the most dominant types of defects, determine defect distribution patterns, identify relationships between variables, and formulate root causes of the problems as a basis for developing recommendations for quality control improvements.

Therefore, field observations are a crucial stage in this research because they provide a factual picture of the welding process in the manufacturing industry. The data obtained through observation was then integrated with the results of processing using Seven Tools so that the analysis was not only based on statistical data, but also supported by actual conditions in the field. This approach is expected to be able to produce more targeted improvement recommendations in an effort to improve the quality of pipe welding results and minimize the level of production defects. The following data processing was carried out after the field observations were carried out:

A. Check Sheet Analysis

Table 3. Welding Defect Classification Data (Check Sheet)

No.	Defect Type	January	February	March	April	May	June	Total
1	Porosity	10	12	14	13	15	16	80
2	Crack	7	8	9	8	10	11	53
3	Undercut	5	5	6	6	7	8	37
4	Lack of Fusion	4	4	5	4	5	5	27
5	Slag Inclusion	2	2	2	2	2	2	12
Total		**28**	**31**	**36**	**33**	**39**	**42**	**209**

Results of 2026 researcher data processing

Based on the inspection data of the pipe welding process during the period of January to June 2026, information was obtained regarding the number of welding joints inspected, the quantity of defective products, and the types of defects occurring during the production process. These data were used as the basis for evaluating welding quality performance and identifying the dominant defect categories. During the research period, a total of 3,090 welding joints were inspected, with 209 defective welding joints identified. The defect rate was calculated by comparing the number of defective products with the total number of inspected welding joints using the following equation:

$$\frac{209}{3.090} x\ 100\% = 6.76\%$$

The calculation results indicate that the overall defect rate during the six month observation period was 6.76%. This value indicates that several products still failed to meet the company's quality requirements, resulting in the need for repair welding activities or product rejection. Therefore, the current quality control system requires further improvement to minimize defect occurrence. The inspection results identified five major welding defect categories, namely porosity, crack, undercut, lack of fusion, and slag inclusion. Among these defects, porosity was identified as the most frequently occurring defect, followed by crack, undercut, lack of fusion, and slag inclusion. The dominance of porosity defects indicates that the welding process is still influenced by several factors, including electrode conditions, material cleanliness, and inappropriate welding parameters.

The defect rate of 6.76% indicates a significant quality issue because it may increase production costs due to rework activities, product rejection, and potential delays in production completion. Therefore, further analysis using the Seven Quality Control Tools, particularly the Pareto Diagram, P-Control Chart, and Fishbone Diagram, is required to identify the root causes of welding defects and determine appropriate corrective actions.

B. Pareto Diagram Analysis

A Pareto diagram was applied to compare the frequency of each welding defect category and determine the defects that should receive priority improvement efforts. Based on the six month defect data analysis, a total of 209 welding defects were identified, consisting of five major defect categories.

Table 4. Pareto Diagram Percentage Analysis

No.	Defect Type	Frequency	Percentage (%)	Cumulative Percentage (%)
1	Porosity	80	38.28	38.28
2	Crack	53	25.36	63.64
3	Undercut	37	17.70	81.34
4	Lack of Fusion	27	12.92	94.26
5	Slag Inclusion	12	5.74	100.00
	Total	**209**	**100.00**	

Results of 2026 researcher data processing

The Pareto analysis results show that porosity was the dominant welding defect, accounting for 80 occurrences or 38.28% of total defects. The second most frequent defect was crack, with 53 occurrences (25.36%), followed by undercut with 37 occurrences (17.70%). The cumulative contribution of the three dominant defects, namely porosity, crack, and undercut, reached 81.34% of the total welding defects. Based on the Pareto principle, these three defect categories represent the main quality problems that require immediate improvement because controlling these defects will provide the greatest impact on reducing overall defect rates. Meanwhile, lack of fusion contributed 12.92%, and slag inclusion contributed 5.74% of total defects. Although these defects occurred less frequently, they should still be controlled to maintain consistent welding quality and prevent future quality deterioration.

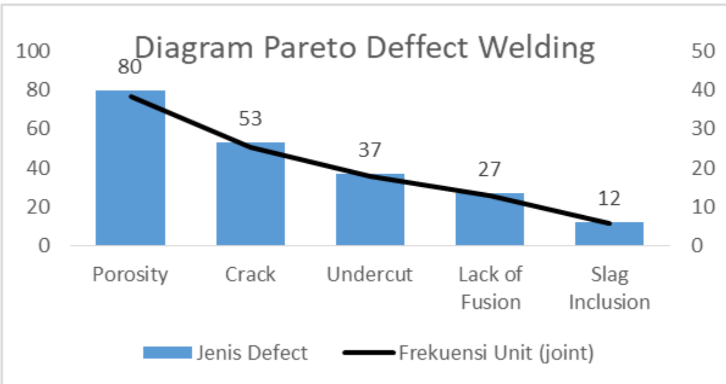

Fig. 2. Pareto Diagram of Welding Defects

The Pareto diagram illustrates the contribution of each welding defect category to the total number of defects occurring during the pipe welding process. Based on the analysis results, porosity was identified as the most dominant defect, with 80 occurrences or 38.28% of the total defects. The cumulative percentage for porosity reached 38.28%, indicating that porosity was the primary factor contributing to the decline in pipe welding quality.

The second most frequent defect was crack, with 53 occurrences or 25.36% of the total defects. When combined with porosity, the cumulative percentage increased to 63.64%. Furthermore, undercut contributed 37 occurrences or 17.70%, resulting in a cumulative percentage of 81.34%. Meanwhile, lack of fusion contributed 12.92%, and slag inclusion represented the lowest defect occurrence, accounting for 5.74%, resulting in a cumulative percentage of 100%.

Based on the Pareto principle (80/20 concept), three major defect categories, namely porosity, crack, and undercut, contributed approximately 81.34% of all welding defects. Therefore, improvement efforts should prioritize these three defect categories because controlling these defects will provide the greatest impact in reducing the overall defect rate and improving pipe welding quality.

C. P-Control Chart Analysis

After completing the Pareto analysis, the next stage was developing a P-Control Chart (P-Chart) to evaluate whether the quality control process implemented in the company was statistically effective and stable. The P-Chart was selected because the welding quality data were attribute-based, where products were classified into defective and non-defective categories.

The calculation steps for developing the P-Chart included:

1. Calculating the defect proportion for each observation period.
2. Determining the center line (Central Line/CL).
3. Calculating the upper control limit (Upper Control Limit/UCL).
4. Calculating the lower control limit (Lower Control Limit/LCL).

Table 5. Number of Welding Joints, Defective Products, and Defect Proportion

Month	Welding Joints	Defective Products	Defect Proportion (p)	Percentage (%)
January	480	28	0.0583	5.83
February	500	31	0.0620	6.20
March	520	36	0.0692	6.92
April	510	33	0.0647	6.47
May	530	39	0.0736	7.36
June	550	42	0.0764	7.64
Total	**3,090**	**209**	**0.0676**	**6.76**

Results of 2026 researcher data processing

Based on the production data from January to June 2026, a total of 3,090 welding joints were inspected, with 209 defective welding joints identified. The center line value was calculated using the following equation:

a. Calculating the P-Chart for January - June 2026. Calculating the central line (CL).

Where:

$\sum np$: Total number of defects

$\sum n$: Total number inspected

$\sum np$: 209

$\sum n$: 3090

$$CL = \frac{\sum np}{n} = \frac{209}{3090} = 0.067$$

b. Calculating the control limit for the monitoring conducted by setting the upper control limit (UCL).

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

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:

$$UCL = 0.067 + 3\left(\sqrt{\frac{0.067\,(3 + 0.067)}{515}}\right) = 0.10$$

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

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

Where:
P = Average welding damage
K = Level of confidence
n = Total Group / Sample

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

$$LCL = 0.067 - 3\left(\sqrt{\frac{0.067\,(3 - 0.067)}{515}}\right) = 0.03$$

d. P-Chart Interpretation

Table 6. P-Chart Control Values for Pipe Welding Defects

Month	Welding Joints	Defective Products	Proportion	CL	UCL	LCL
January	480	28	0.0583	0.067	0.10	0.03
February	500	31	0.0620	0.067		
March	520	36	0.0692	0.067		
April	510	33	0.0647	0.067		
May	530	39	0.0736	0.067		
June	550	42	0.0764	0.067		

Results of 2026 researcher data processing

Based on the P-Control Chart calculation results presented in Table 5, the obtained values were Center Line (CL) = 0.067, Upper Control Limit (UCL) = 0.10, and Lower Control Limit (LCL) = 0.03. The defect proportions during the observation period were 0.0583 in January, 0.0620 in February, 0.0692 in March, 0.0647 in April, 0.0736 in May, and 0.0764 in June. All defect proportion values were located between the upper and lower control limits. Therefore, statistically, the pipe welding process remained within the acceptable control range (in statistical control). This indicates that the variation occurring during the production process was still classified as normal variation or common cause variation, and no significant abnormal deviation was detected (Herryandie & Maharani, 2023).

Although the welding process remained statistically controlled, the analysis revealed an increasing trend in defect proportion from 0.0583 in January to 0.0764 in June. This increase occurred simultaneously with the rise in production volume, where the number of welding joints increased from 480 joints in January to 550 joints in June. This condition indicates that increased production capacity may potentially lead to higher defect occurrence if it is not supported by stronger process monitoring and quality assurance activities. Therefore, although the process is still statistically stable, the company needs to pay attention to the increasing defect trend to prevent future quality deterioration and ensure that defect levels remain within acceptable control limits. The P-Chart results for the January–June 2026 period are presented in the following table and graphical representation.

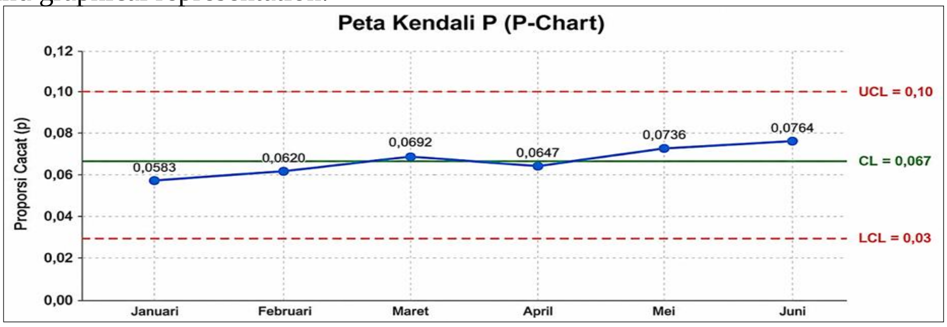

Fig. 3. P-Control Chart of Welding Defects

The results of the P-Chart analysis indicate that the quality control system implemented by the company has been able to maintain the stability of the pipe welding process. However, the effectiveness of the process can still be improved to reduce the average defect proportion. Based on the previous analysis, the dominant welding defects identified were porosity, crack, and undercut (Nurjaman et al., 2024)..

Therefore, improvement strategies should primarily focus on controlling and minimizing the occurrence of these three defect categories. The company is recommended to improve operator competency through continuous training programs, ensure that all welding activities comply with the Welding Procedure Specification (WPS), conduct inspections of electrode and material conditions before the welding process, and implement regular preventive maintenance programs for welding equipment. These improvement actions are expected to reduce the proportion of defective products, improve production effectiveness and efficiency, and ensure that the produced pipe welding joints consistently meet the company's quality standards.

e. Cause and Effect Analysis (Fishbone Diagram)

A fishbone diagram is used to identify the root causes of defects in the pipe welding process. The analysis is based on six main factors (6M): Man, Machine, Material, Method, Measurement, and Environment. For more details, see the following cause effect diagram (Hamzah et al., 2024) :

a) Workers (People), namely those directly involved in the production process.

b) Raw Materials (Materials), namely the components used to produce a finished product.

c) Tools, namely the various equipment used during the production process.

d) Methods, namely the work methods that must be followed in the production process.

e) Environment, namely the conditions surrounding the production site that directly or indirectly affect the production process.

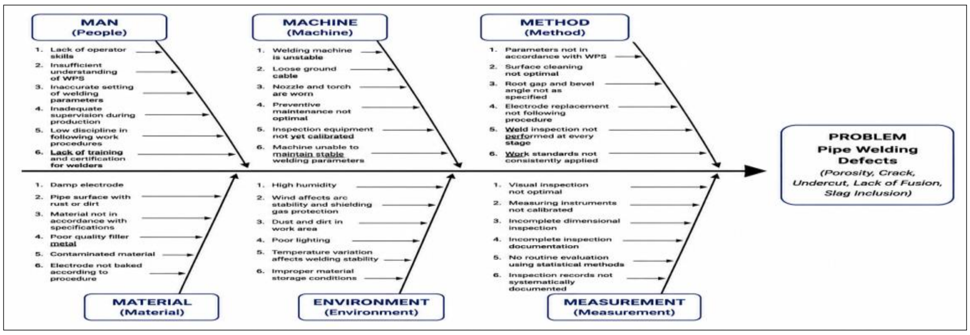

Figure 4. Fishbone Diagram

The following are the results of the fishbone diagram:

a) Man (Operator)

The Man factor refers to workers or operators directly involved in the welding production process. Operator competency, experience level, welding skills, and compliance with standard operating procedures may significantly influence welding quality. Lack of training, operator negligence, or incorrect welding techniques can increase the possibility of defect occurrence.

b) Material

The Material factor refers to the raw materials and supporting components used during the welding process to produce finished products. Material conditions, surface cleanliness, material composition, and storage conditions may affect welding performance. Poor material quality or contamination on the welding surface can contribute to defects such as porosity and lack of fusion.

c) Machine (Equipment)

The Machine factor includes all equipment and tools used during the welding process. Welding machine performance, equipment calibration, maintenance conditions, and stability of welding parameters influence the consistency of welding results. Inadequate machine conditions may cause unstable welding processes and increase defect occurrence.

d) Method

The Method factor refers to the working procedures, welding techniques, and production methods applied during the welding process. Inconsistent implementation of welding procedures, inappropriate parameter settings, or deviations from the Welding Procedure Specification (WPS) may become potential causes of welding defects.

e) Measurement The Measurement factor relates to inspection methods, measurement accuracy, and quality monitoring activities performed during the production process. An ineffective inspection system may result in delayed defect detection and reduce the effectiveness of quality control activities.

f) Environment

The Environment factor refers to workplace conditions that may directly or indirectly influence the welding process. Environmental factors include temperature, humidity, cleanliness of the working area, ventilation conditions, and workplace organization. Poor environmental conditions may affect welding stability and product quality. The results of the Fishbone Diagram evaluation identified several potential root causes affecting pipe welding quality. The analysis showed that welding defects were mainly associated with operator competency, inconsistency in welding parameter control, material preparation conditions, equipment performance, adherence to welding procedures, inspection effectiveness, and workplace environmental conditions.

f. Analysis Results and Discussion

Based on data processing using the Seven Quality Control Tools method, it was discovered that the pipe welding quality control process still showed some products that did not meet company quality standards. During the period from January to June 2026, a total of 3,090 weld joints were produced, with 209 pipe welds resulting in defects, representing 6.76% of total production.

1) Analysis using the Check Sheet showed five types of defects occurring during the welding process: porosity, cracks, undercuts, lack of fusion, and slag inclusions. This data indicates that the welding process still experiences quality variations, requiring continuous quality control to minimize the number of defects.

2) Analysis using the Histogram and Pareto Chart showed that porosity was the most prevalent defect type, accounting for 80 occurrences, or 38.28% of the total defects. The next most common defects were cracks (53 occurrences (25.36%), undercuts (37 occurrences (17.70%), lack of fusion (27 occurrences (12.92%), and slag inclusions (12.74%). Based on the Pareto principle, the three most common defects—porosity, cracks, and undercuts—contributed to 81.34% of the total defects. These results suggest that the company can focus quality control efforts on these three types of defects, as they will have the greatest impact on reducing the defect rate.

3) Analysis using a P-Chart shows that all monthly defect proportions fall between the upper control limit (UCL = 0.10) and lower control limit (LCL = 0.03), with a centerline value (CL = 0.067). This indicates that the pipe welding process remains under statistical control, as no observation points fall outside the control limits. However, the graph shows a trend towards an increasing proportion of defective products from January to June. Although process variation is still considered normal (common cause variation), the company needs to take corrective action to prevent an increase in the defect rate in the next production period.

4) Based on the results of the Fishbone Diagram, the main causes of welding defects stem from six factors: human, machine, method, material, measurement, and environment. Human factors are related to a

lack of operator competence and non-compliance with the Welding Procedure Specification (WPS). Machine factors are caused by unstable welding machine conditions and suboptimal preventive maintenance implementation. Method factors are influenced by substandard welding parameter settings, while material factors are related to the use of damp electrodes and contaminated material surfaces. In addition, environmental factors such as humidity and work area conditions, as well as measurement factors such as suboptimal inspections, also affect the quality of welding results. Therefore, the company is advised to improve operator competence through training and certification, consistently implement the WPS, conduct regular machine maintenance, improve material and electrode storage systems, and increase the effectiveness of quality inspections. By implementing these recommendations, it is hoped that the defect rate in pipe welding results will decrease, product quality will improve, and the production process will become more effective and efficient.

IV. CONCLUSION

Based on the overall analysis results, it can be concluded that the quality control of the pipe welding process still requires improvement even though the production process is statistically under control. This is because process stability does not necessarily indicate that the quality level has met the company's targets. Therefore, the company needs to implement a continuous improvement strategy by increasing operator competency through welding training and certification, consistent application of Welding Procedure Specifications (WPS), preventive maintenance of welding machines, material quality control before use, electrode storage according to standards, increasing the effectiveness of quality inspections, and utilizing statistical data periodically as a basis for decision making. The implementation of these recommendations is expected to reduce the level of product defects, reduce costs due to rework and repair welding, increase production process efficiency, and produce pipe welding that has quality in accordance with manufacturing industry standards. Thus, the research objectives of identifying types of defects, determining the most dominant types of defects, analyzing the main causes of defects, and developing improvement proposals using the Seven Quality Control Tools method have been systematically achieved and can be used as a reference for companies in improving the effectiveness of their quality control systems.

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