WELDING QUALITY CONTROL USING THE FAILURE MODES AND EFFECTS ANALYSIS (FMEA) METHOD AT PT. X

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ABSTRACT

This research aims to identify and analyze defects in the welding process at PT. X uses the FMEA method. The primary defects found were cracks, porosity, spatter, and undercut. The leading causes of crack defects are poor material conditions, porosity caused by inadequate facilities, spatter due to inappropriate parameter settings, and undercut due to lack of supervision. The highest RPN value is crack, with a score of 288, followed by porosity (280), spatter (196), and undercut (175), indicating that crack and porosity require special attention. Improvement strategies include improving material quality and inspection procedures for cracks, improving facilities for porosity, operator training and automated monitoring for spatter, and increased monitoring for undercuts. Based on the visualization of the Pareto diagram, the number of defects that frequently occurred was spatter in 16 cases with a percentage of 36%, followed by undercut in 11 cases (25%), crack in 9 cases (21%), and porosity in 8 cases (18%). This data was collected from production that experienced defects from January – April 2024. The Pareto diagram shows that spatter is the most frequently occurring defect, even though it has a lower RPN than crack and porosity. Therefore, the repair priority must remain on crack and porosity because of their significant impact on weld quality. Implementing the proposed improvement strategy is expected to reduce the risk of failure and increase the efficiency and quality of the welding process at PT. X.

Keyword: FMEA, welding defects, RPN, repair strategy, Pareto diagram

Introduction

The characteristics of the business world environment can be seen not only from high levels of productivity and low levels of product and service prices but also from the quality of products or services, which can be in the form of comfort, convenience, accuracy, and speed in achieving them. To maintain consistent quality of products and services, it is necessary to maintain quality control over the process activities (Ariani, 2016).

PT. X is a BUMS shipbuilding company in Indonesia that has played an essential role in developing the Indonesian maritime industry, focusing on ship production and repair. These two activities are carried out through several stages, including welding (Wulandari, 2017). Several welding defects were discovered during the production and repair processes in the welding sector. The following is the number of defects for January 2024 up to end of April 2024 (see Table 1).

Welding quality control at PT. X is currently considered less than optimal, in this case quality control on the principle of inspection and corrective action PT. X gets a score of 2 from 1 - 10. This explains that PT. X still lacks procedures to conduct performance audits of its environmental management system and its component elements. Non-conformities have not been identified optimally, as a result, corrective or preventive actions cannot be effectively implemented (Pujotomo & Subekhi, 2014). Based on the analysis and discussion of problems at PT. X, the repair workshop section at the shipyard in the welding inspection section received a risk value of 6 and of course this is a note for the company so that it can improve efforts to control the quality of the welding process and products (Mahendar & Pujutomo, 2019).

Table 1. Welding defect

Defect	Month				Total
	January	February	March	April	
Cracks	5	1	1	2	9
Spatter	7	1	4	4	16
Porosity	1	4	0	3	8
Undercut	1	5	1	4	11
Total	14	11	6	13	44

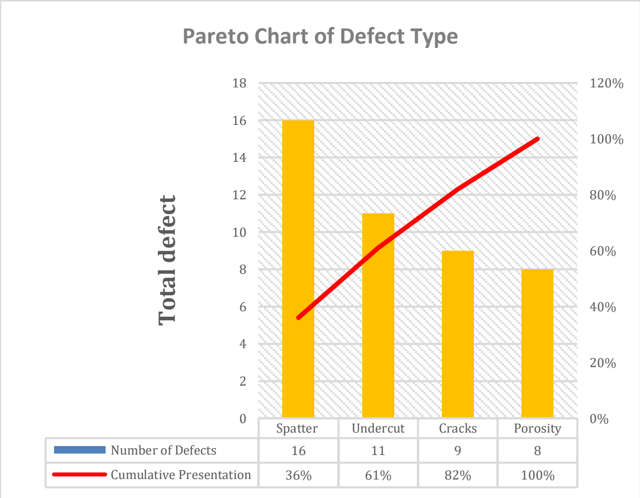

Figure 1. Pareto Diagram – Type of Defects

The visualization of the Pareto diagram (see Figure 1) shows that the number of defects frequently occurring is spatter in 16 cases with a percentage of 36%. Then, there were 11 undercut defects, with a percentage of 25%. Crack-type defects occurred in 9 cases, with a 21% percentage. Lastly, there are eight types of porosity defects with a percentage of 18%.

Based on the description above, this research used the Failure Mode and Effects Analysis (FMEA) method. Failure Mode and Effect Analysis is an improvement strategy used to identify and assess risks or Risk Priority Numbers (RPN) and determine priorities that must be followed up. The primary purpose of using the FMEA method is to identify potential failure modes in a sector or system, evaluate the subsequent effects on the performance of a procedure or system, and the consequences which are in the form of recommendations for a strategy to eliminate or minimize the possibility of occurrence, severity, and improve the system—detection of failure modes in specific sectors (Lo & Liou, 2018).

This research can create a deeper understanding of potential risks and problems that may arise in the welding process. In addition, strategic recommendations will be developed to improve efforts to control welding quality, which is expected to increase PT. X's competitiveness in the shipping industry company.

Methodology

This research was carried out in stages to identify failures experienced in the welding process. So, in the research flow, primary and secondary data are needed, as obtained through field studies. After the information is obtained and processed, a welding process workflow will be prepared for the company under study, while identification in this research is about welding quality control.

After understanding the process involved, problem identification can be narrowed by making a fishbone diagram to look for the root of the problem in factors that can potentially cause failure. Qualitative analysis was done by conducting direct interviews with related objects or purposive sampling. Then, the FMEA analysis table will be filled in to find the RPN values.

Survey Data

In this research, the interview process involved five key individuals at PT. X, namely the Head of QA/QC, QC personnel, welding inspector, replating supervisor, and certified welders. The purposive sampling method with primary, essential, and supporting sources was used to ensure the data obtained was relevant. Interview instruments include a list of questions compiled by the researcher, a field notebook, and tools such as a camera and voice recorder to facilitate accurate data transcription. Some of the discussion topics in the interview process are outlined in Table 2.

Table 2. Topic Interview

No	Topic
1	Welding Process
2	Use of the FMEA Method
3	Personnel roles and involvement
4	Potential Failure and Impact
5	Risk Evaluation and Action Prioritization
6	Recommendations and Improvements
7	Implementation and Evaluation of Preventive Measures

FMEA Worksheet

Qualitative analysis using the FMEA worksheet focuses on determining the severity, occurrence, and detection values, which will be used to calculate the RPN. RPN is the product of Severity, Occurrence, and Detection. It describes the potential for failure and its impact, with RPN values ranging from 1 to 1000.

Table 3. Severity Worksheet

Effect	Severity effect for FMEA	Rank
There isn't any	Has no side effects	1
Very small	There is no immediate effect	2
Small	Limited effects	3
Very low	Needs a little rework	4
Low	Needs a lot of reworks	5
Currently	Product is damaged	6
Tall	Causing the equipment to be disrupted	7
Very high	Causing the machine to be damaged	8
Dangerous with warning	Causes the engine to completely stop	9
Dangerous without warning	Resulting in machine disruption and threatening operator safety	10

Table 4. Occurrence Worksheet

Effect	Occurrence Effect for FMEA	Rank
Low	Small Number of Defects	1-3
Currently	One-time failure	4-6
Tall	Repeated Failure	7-8
Very high	Irreversible Failure	9-10

Table 5. Detection Worksheet

Effect	Detection Effect for FMEA	Rank
Almost impossible	The controller can barely carry out the detection which causes the failure	10
Very rarely	The inspector cannot detect the failure	9
Seldom	It is very difficult for controllers to detect the cause of failure	8
Very low	Control performance is very weak	7
Low	Weak failure detection control capabilities	6
Currently	moderate failure detection control	5
A bit high	Controller errors cause the detection capability to be quite high	4
Tall	The ability of the control device to detect the cause of failure is high	3
Very high	High controller errors lead to very high detection capabilities	2
Almost certainly	Current control tools are almost certainly capable of detecting the cause of failure	1

The higher the RPN value, the greater the probability of failure. Therefore, failure modes with the highest RPN are the main priority.

Severity, namely the possible consequences if a failureoccurs. Details of severity values are in Table 3.

Occurrence, namely the probability of a non-conformity occurring or the frequency with which failures occur. Details of the occurrence values are in Table 4.

Detection that is, the probable probability of the failure can be detected before the effects of the failure effect can be realized. Details of the Detection values are in Table 5.

Result and Discussion

At this stage, data analysis was carried out, which was obtained through various processes in this research, starting from primary data to secondary data. Based on the research methodology, the first stage of this research was data analysis using cause and effect diagrams or fishbone diagrams of the types of defects found at PT. X. However, to be able to compile a fishbone diagram, identification of the cause of welding defects from five factors that can affect disability, namely humans, the environment, and materials. Methods and machines. Using the five whys analysis and 5W + 1H method, the root causes of defects can be identified, and the process of determining the relationship between the root causes of the problem can be carried out. The following are the results of the five whys analysis method based on five factors:

Man

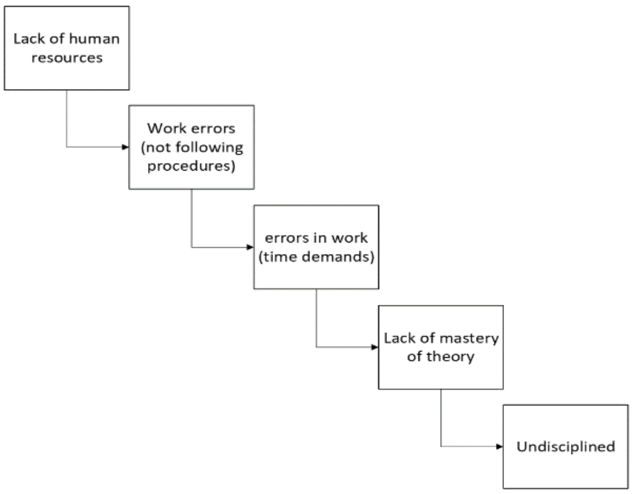

Figure 3. Man Factor

The human factor is caused by a lack of human resources in the welding sector, errors in work caused by non-compliance with work procedures, errors in work caused by demands on production time, lack of mastery of theory, and employee indiscipline.

Environment

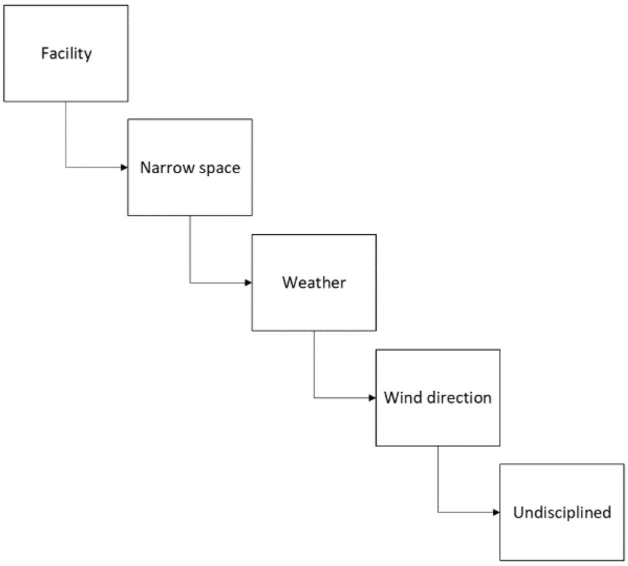

Figure 4. Environment Factor

Environmental factors are caused by a lack of supporting facilities, limited workspace, weather, wind direction, and room temperature.

Material

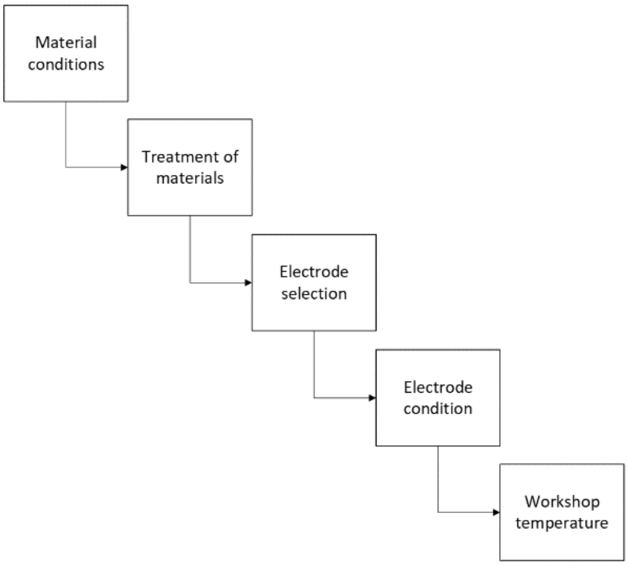

Figure 5. Material Factor

Material factors are caused by the condition of the Material to be welded, the treatment of the Material, inappropriate electrode selection, electrode condition, and type of welding material.

Method

Method factors are caused by inappropriate work methods, working methods, welding positions, roles in supervision, and guidelines in quality control that still need to be effective.

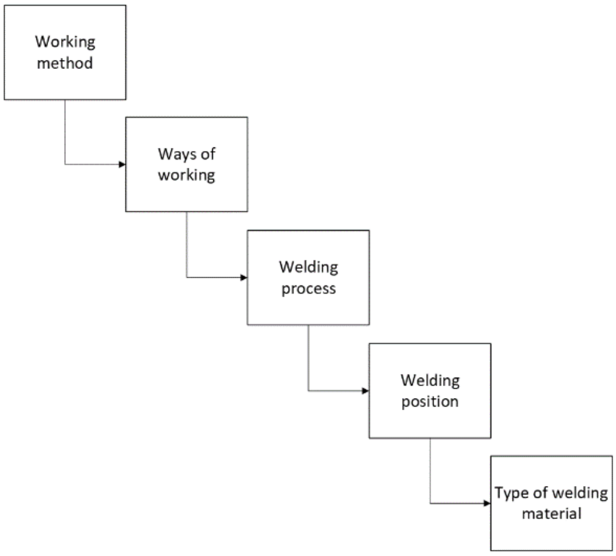

Figure 6. Method Factor

Machine

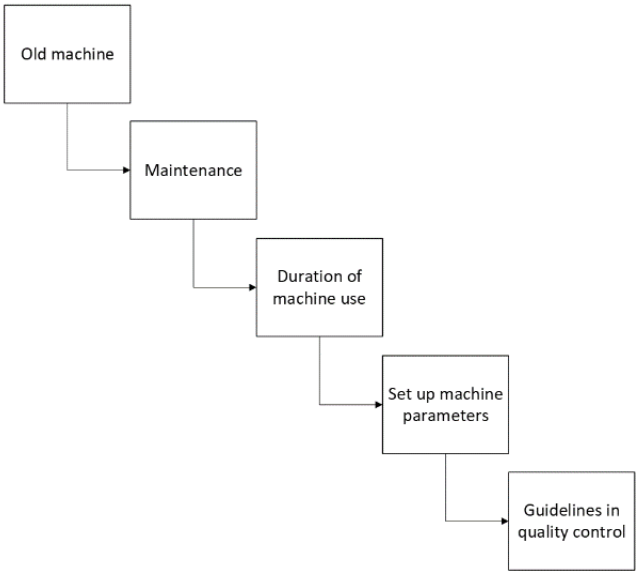

Figure 7. Machine Factor

Machine factors are caused by outdated machine conditions, lack of maintenance processes, duration of machine use, incorrect machine parameter setup, and how the machine is used.

After carrying out the five whys analysis method, the next stage is to create a causes and effects diagram or fishbone to find out the root cause of the disability with five factors. The figure 7 is a fishbone diagram based on the five whys analysis method, which was carried out on the causes of crack, spatter, porosity, and undercut defects at PT. X.

Risk Analysis and RPN assessment

Four types of defects are identified as influencing the welding quality control process at PT.X, including crack, spatter, porosity, and undercut.

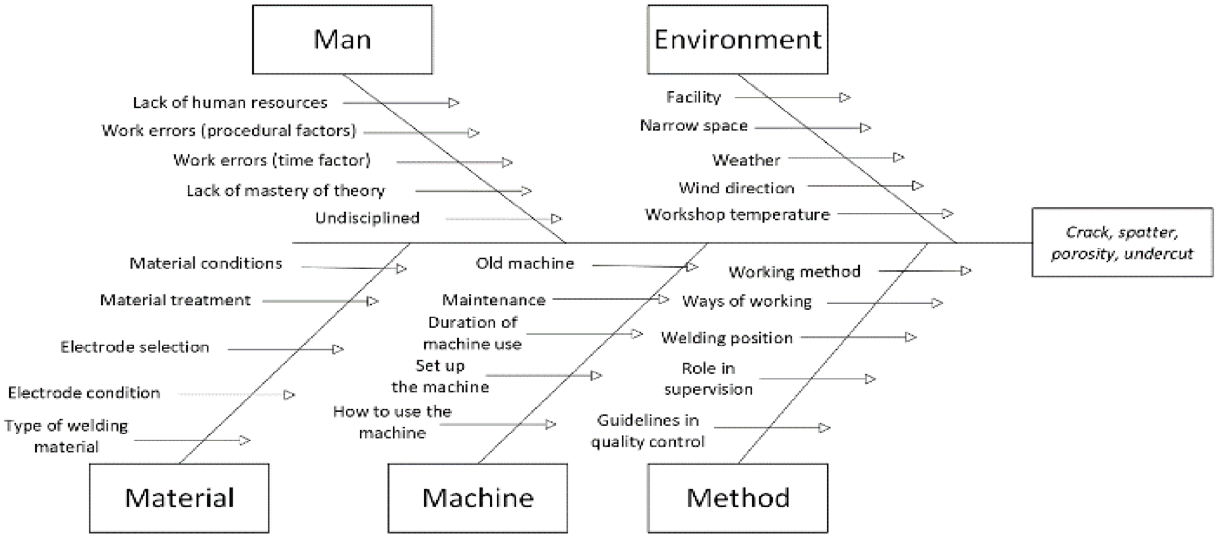

Figure 7. Cause-effect diagram

Each of these defect modes is analyzed to understand the process of why and how the failure occurred and what impact it has on the welding results. Based on the identified failure modes, several failure models were analyzed using the FMEA method to determine the RPN seen in Table 5.

Table 5. Failure Mode and Effect Analysis for defect

Potential Failure Mode	*Potential Effect of Failure*	*SEV*	*Potential Cause*	*OCC*	*Current Control*	DET	RPN
Crack	There will be a significant decrease in the material structure, causing the product to become damaged if left untreated	6	The cooling process is too fast	7	Maximize WI's role in supervision during the process	3	126
			Residual stress	4	Perform post weld heat treatment (PWHT)	5	120
			Poor material condition	8	Carrying out material inspection at the welding preparation stage	6	288
Spatter	Affects aesthetics and defects in the material will be covered by splashes making it difficult to inspect	4	Improper parameter set up	7	Follow the procedures in WPS	7	196
			Travel speed is too fast	7	Conduct briefings for workers	4	112
			Improper electrode selection	3	Follow the specifications listed in the WPS	5	60
Porosity	It will damage the material, such as corrosion from within the welds and if left untreated it will crack when the material is exposed to a load	5	Poor material condition	8	Inspection of material inventory	6	240
			Improper electrode selection	2	Maintain electrode quality	5	50
			Facilities that are less supportive	8	Carry out routine repairs and maintenance of facilities	7	280
Undercut	Will reduce the resistance of the welded joint to cyclic loads (repeated loads in certain cycles)	5	Travel speed is too fast	7	Maximize the supervision and training functions of welders	2	70
			Improper electrode angle	3	Training and briefing of welders	3	45
			Lack of supervision	7	Carrying out evaluations on the supervision system	5	175

In the table above, it is known that the highest RPN value lies in the crack defect type, namely 288, with the potential error being poor material conditions when carrying out the welding process. Second, the porosity defect scores 280, with the potential error lying in inadequate supporting facilities. The spatter-type defect has a score of 196, with the potential error being that the operator set up parameters that were not correct or in accordance with the WPS. For the undercut type of defect, the highest score was 175, with the potential error being a lack of supervision during the welding process.

Based on the analysis and evaluation of types of failure and calculation of RPN values, the next stage is to develop strategic recommendations and corrective actions to reduce or eliminate the types of failure that occurred previously. This preparation was carried out based on the highest RPN value and the implementation of the Pareto diagram to determine the priority scale for action based on the percentage of several types of defects that have a high frequency that occurs during the welding process at PT. X.

Interpretation of FMEA Results and Pareto Diagrams

In this research, the results of FMEA and the Pareto diagram are the primary references for identifying, evaluating, and determining failure priorities in the welding process at PT. X. Interpreting FMEA results and Pareto diagrams provides in-depth insight into the factors influencing welding quality.

Interpretation of FMEA Analysis

In the interpretation of FMEA results, potential failures in the welding process are described, and analysis of the impact and potential causes of each failure is based on the type of defect and the highest RPN score for each type of defect, and There are proposals for corrective action for each failure. Following are the FMEA results for each type of failure:

Crack (RPN: 288) - Poor material condition

Crack defects have the highest RPN score; the potential cause is poor material conditions during the welding process. If a load is applied, this type of crack defect will have a severe impact, especially on the structure and strength of the welded joint. The following are recommended repair strategies for crack defects:

1. Improved Material Quality: Material Inspection: Use UT or MPT before use. Supplier Certification: Make sure suppliers are certified and undergo regular audits.
2. Proper Storage of Materials: Storage Conditions: Use an area protected from moisture and contamination with a desiccant. Labeling and Monitoring: Implement a labeling system for material age and condition.
3. Preheating Process: Preheat to reduce internal stress. Technological Innovation: Use efficient induction heating.
4. HVAC Innovation: Temperature and Humidity Control: Use advanced HVAC for temperature and humidity stabilization. Real-time Monitoring: Install environmental sensors for real-time condition monitoring.

Porosity (RPN: 280) - Facilities that are less supportive

Porosity defects have a high RPN score of 280. Unsupportive facility conditions are a potential cause of this failure. Porosity in the welding process can reduce the Material's resistance to corrosion and structural strength if left unchecked. The following are recommended repair strategies for Porosity defects:

1. Ventilation System Repair: Modern Ventilation System: Install a sophisticated ventilation system with air filtration to reduce gas contamination. Environmental Monitoring: Use environmental sensors for real-time monitoring of air, temperature, and humidity.
2. Work Environment Control: Workspace Conditions: Improve workspace cleanliness to prevent contamination. Technological Innovation: Use a particular HVAC system for the welding area.
3. HVAC Innovation: Integrated HVAC System: Use HVAC that regulates temperature and humidity and is equipped with air filtration to reduce harmful particles and gases. Energy Optimization: Implementing energy-saving HVAC with automatic systems for adjusting environmental conditions.

Spatter (RPN: 196) - Improper parameter setup

Spatter defects have a high RPN value, and the potential cause is the operator setting up parameters on the machine incorrectly or not in accordance with the WPS. The following are recommended repair strategies for spatter defects:

1. Operator Training: Conduct scheduled training for welding operators regarding parameter settings according to the WPS. AR Innovation: Augmented Reality technology provides operators with interactive visual guidance.
2. Parameter Setting Automation: Use a welding machine that can calibrate parameters automatically according to the WPS. Simulation Software: Utilize simulation software to test parameters before implementation in accurate welding.

Undercut (RPN:175) – Lack of supervision during the welding process

Undercut defects have a high score of 175, and the leading cause of undercut defects is a lack of supervision during the welding process. Undercuts in welding can reduce structural durability because the Material is eroded. The following are recommended repair strategies for undercut defects:

1. Real-Time Monitoring: Monitoring System: Install cameras and sensors to monitor the welding process directly. Machine Learning Innovation: Machine learning technology automatically detects defects during welding and provides immediate feedback to the operator.
2. FMEA Method: Failure Recording: Increase failure recording every production or month for cause analysis. Priority Recommendations: Implement recommendations from FMEA based on the highest RPN score.
3. Supervisor Training and Certification: Certification Program: Provide certification to welding supervisors to ensure competency. Training Innovation: Use virtual simulations to train supervisors in complex supervisory situations.

Interpretation of Pareto Diagrams

Interpretation of Pareto diagrams for defects in the welding process at PT. X highlights the main findings as follows:

Spatter has the highest frequency (36%), indicating that this problem often occurs in welding, although it has a relatively low impact based on the RPN value. However, due to its high frequency, spatter is a top priority for repair. Apart from spatter, undercut (25%), crack (21%), and porosity (18%) also have a significant impact on welding quality, even though their frequency is lower. Although not as common as spatter, these four types of defects require proper repair to reduce or eliminate failures in the welding process. By focusing on spatter as the main priority and proper handling of undercuts, cracks, porosity, and PT, X is expected to improve the quality and reliability of their welding significantly.

Conclusion

Welding process at PT. X faces significant defects like cracks, porosity, spatter, and undercuts. Based on analysis using the Five Whys Analysis method, fishbone diagram, and 5W + 1H approach, the leading causes of each defect can be identified, such as cracks caused by poor material conditions, porosity related to inadequate facilities, spatter caused by inappropriate parameters, and undercut due to lack of supervision during the welding process. The RPN analysis results show that crack defects have the highest RPN with a score of 288, followed by porosity with a score of 280, spatter with a score of 196, and undercut with a score of 175. Even though spatter has the highest frequency of occurrence, based on the diagram visualization Pareto, the number of defects that frequently occurred was spatter, 16 cases with a percentage of 36%. Then, undercut defects occurred in 11 cases, with a 25% percentage. Crack defects were recorded in 9 cases with a percentage of 21%, while porosity defects were recorded in 8 cases with 18%.

Therefore, to improve quality, PT. X must prioritize improving controls and procedures to reduce the incidence of spatter and undercut defects while still paying attention to improving material quality and facilities to reduce cracks and porosity in the welding process.

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