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Journal homepage: https://talenta.usu.ac.id/jsti

Quality Optimization of Fuel Transportation Tank Production Process Using Design of Experiment (DoE) at PT. Sejahtera Mandiri Pekanbaru

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ARTICLE INFO

Article history:
Received 4 December 2024
Revised 7 January 2025
Accepted 19 January 2025
Available online 29 April 2025

E-ISSN: 2527-9408
P-ISSN: 1411-5247

Periment How to cite:
Putra, A. M., Anizar., & Panjaitan, N., (2025). Quality Optimization of Fuel Transportation Tank Production Process Using Design of Experiment (DoE) at PT. Sejahtera Mandiri Pekanbaru. *Jurnal Sistem Teknik Industri*, 27(2), 105-116.

ABSTRACT

With an average error rate of 2.3%, the production of fuel transportation tanks at PT Sejahtera Mandiri Pekanbaru has defects that exceed the 2% tolerance level. Porosity, undercut, and crack are the most frequent types of defects that result in additional cost and rework time. This study aims to improve the quality of the fuel transportation tank production process at PT Sejahtera Mandiri Pekanbaru. Data shows that production errors such as porosity, undercut, and cracks have an impact on the quality of the final product. This study used a 2^k full factorial design to find the main components that affect the quality of welding results. The results show that operator certification and electrode temperature oven parameters have a great influence on manufacturing defects. Maximizing the use of electrode oven at 260°C-425°C for 1 hour, electrode moisture can be eliminated and porosity can be reduced. The DoE approach is good for finding and optimizing production features to reduce defect rates. This study suggests operator training and control of process parameters to improve welding quality.
Keyword: Quality Control, Design of Experiment, Anova, Fuel Transportation Tank

ABSTRAK

Dengan tingkat kesalahan rata-rata 2,3%, produksi tangki transportasi BBM di PT Sejahtera Mandiri Pekanbaru memiliki cacat yang melampaui tingkat toleransi 2%. Porositas, undercut, dan retak adalah jenis cacat yang paling sering terjadi yang mengakibatkan biaya tambahan dan waktu pengerjaan ulang. Studi ini bertujuan untuk meningkatkan kualitas proses produksi tangki transportasi BBM di PT. Sejahtera Mandiri Pekanbaru. Data menunjukkan bahwa kesalahan produksi seperti porosity, undercut, dan retakan berdampak pada kualitas produk akhir. Studi ini menggunakan desain faktorial penuh 2^k untuk menemukan komponen utama yang mempengaruhi kualitas hasil pengelasan. Hasil penelitian menunjukkan bahwa sertifikasi operator dan parameter oven suhu elektroda memiliki pengaruh besar terhadap cacat produksi. Memaksimalkan penggunaan oven elektroda pada suhu 260°C–425°C selama 1 jam, kelembaban elektroda dapat dihilangkan dan porosity dapat dikurangi. Pendekatan DoE baik untuk menemukan dan mengoptimalkan fitur produksi guna mengurangi tingkat cacat. Penelitian ini menyarankan pelatihan operator dan pengendalian parameter proses untuk meningkatkan kualitas pengelasan.
Kata Kunci: Pengendalian Kualitas, Design of Experiment, Anova, Tangki Transportasi BBM

1. Introduction

A business plan that focuses on quality control is one method that organizations in today's globalized world can use to overcome the various obstacles they face when assessing industry progress. By reducing the number of defective goods and ensuring consistent quality, quality control is an important management technique to ensure products meet high requirements after purchase. Products meeting high quality standards will strengthen customers' trust in the company. Focusing on the quality of the product, the process and the end result, companies can experience positive benefits, namely with a competitive advantage and the ability to expand the market share they currently have [1].

Quality control is very necessary to be applied to ongoing process activities. The development of a good and effective production system can overcome problems related to product quality so that incidents such as previous mistakes do not occur again. This can be the basis for evaluating the quality of product production based on inspection by checking goods meet standards and rejecting goods that do not meet standards [2].

PT Sejahtera Mandiri Pekanbaru is a company engaged in manufacturing car body fabrication, provision of spare parts, service or rejuvenation. This company cooperates with PT Pertamina Tbk, and must be able to meet the standards desired by its clients. This company operates in Riau Province. The process or stage in the manufacture of fuel transportation tanks is welding using the SMAW method. Welding is the main process in the manufacture of fuel transportation tank products, so this production process is responsible for the welding production department. Welding is a technique used to unite two materials or requires filler material such as electrodes to obtain sustainable and better connection results [3].

Crack is a defect with a gap that is too wide or open, so it requires too much current and uses more material. The welding production process must be carried out repeatedly so that the crack reaction that arises can be better than before [4]. One of the causes of repeated welding is not using the right electrode. In addition to these causes, there are other causes such as welding fluid, uncut products that cause welding debris to be trapped in the unfilled material groove called undercut accompanied by a very fast welding motion speed [4]. Porosity is a defect that has small holes or pores on the surface or inside the welding results and improper electrode selection [5]. In addition, the cause of defects in the welding process is caused by materials and humans.

The material used in the welding process is ASTM A36 plate 4mm thick and the electrode type with low hydrogen content E7018 is very sensitive to water absorption. This inorganic coating is designed to contain little moisture so it requires careful storage. The electrode absorbs water beyond the permissible limit, so the electrode must be heated in order to remove the water contained therein [6]. Welding results generally depend heavily on the skill of the welder [7]. Certified welders will be able to compete in fierce competition. In addition, human factors also affect the production of these products. Therefore, the human factor is also a very influential factor in maintaining product quality [8].

Based on the above factors become the cause of defects, thus affecting the quality of products produced. Products from the production of PT Sejahtera Mandiri Pekanbaru in the form of defects from the production process of fuel transportation tanks exceed the maximum limit desired by the company. The following information on the amount of defective product data can be seen in Table 1.1

Table 1. Number of Defective Products from 2019-2024

Year	Production Realization (Unit)	Defective Products (Unit)			Total Defects (Unit)	Percentage of Defects (%)
		Porosity (≤1 mm)	*Undercut* (≤1 mm)	*Crack* (*No Crack*)		
2019	76	0	1	0	1	1.3
2020	82	1	1	0	2	2.4
2021	71	1	0	0	1	1.4
2022	84	2	1	1	4	4.8
2023	70	1	1	0	2	2.9
2024	83	1	0	0	1	1.2
Amount	466	6	4	1	11	14
Average						2.3%

Source: PT. Sejahtera Mandiri Pekanbaru

Based on observations and field data, PT Sejahtera Mandiri Pekanbaru experienced problems during the production process of fuel transportation tank products, so that welding defects did not comply with the established standard, namely AWS D1.1 / D1.1 M: 2020 (An American National Standard). This type of defect is mostly found in fillet joints, namely porosity exceeding the maximum tolerance of 1 mm with a total of 6 units and undercut exceeding the maximum tolerance of 1 mm with a total of 4 units and this type of crack is also not permitted in any form of welding totaling 1 unit. The company data of PT Sejahtera Mandiri Pekanbaru in Table 1 explains that the average defect percentage defect rate is 2.3%, namely defects that exceed the product tolerance limit determined by the company which is 2%. The highest average defect rate in 2022 is a total of 4 units with a defect percentage of 4.8%. The lowest average defect rate in 2024 is a total defect of 1 unit with a percentage of 1.2%. The high percentage of defect rate defects in the last 6 years the company has suffered losses. The company needs to anticipate what factors cause these losses.

The quality control department anticipates that undercut, porosity and crack defects exceeding the tolerance limit must be repaired, so they need to be welded and re-grinded. The company incurs losses in terms of time, material and labor. Fuel transportation tank products are repaired, which will cause the material to become brittle and prone to deformation resulting in changes in shape or warping, metallurgical changes, thermal changes, and structural changes. Structural changes occur because the mechanical properties of the material change [9].

Based on previous research applying Design of Experiment by Cao et al., [10], one can test and optimize multiple variables at the same time, accelerating the discovery and optimization process while saving valuable laboratory time and resources. Combining data analysis with machine learning makes a difference. Research conducted by Bonetto et al., [11] namely characterization analysis shows that the chemical structure of the adsorbent has many oxygenated functional groups and a good morphology for dye removal. Research by Wahab et al., [12] obtained the results of extracted Zerumbet. The effect of extraction temperature and time was found to be significant on all responses with p values <0.05. Research by Carvalho et al., [13] that a gel consisting of 10% fucoidan, 3% chitosan, and 5% collagen was prepared at 80°C. Research by Sani Inuwa Lamido et al., [14] the linear effect of all factors was significant, with P values of 0.0050, 0.0062 and 0.0003, respectively.

One approach that can help solve the problems that occur in this company is to use Design of Experiments (DoE). Design of Experiments (DoE) as a numerical procedure can control and carry out scientific research linking changes in experimental variables to determine their effect on certain responses. The smallest illustrative dimension, optimal data can be obtained by simply adjusting the initial variables [15]. Starting with a 2^k factorial or 2(k-p) fractional factorial experiment and adding a center point is a commonly recommended approach to identify whether process variables have a curvilinear effect on the response or quality of concern [16]. The 2^2 complete factorial design or 2 area design means that this design is the simplest form with 2 x 2 = 4 trials covering all combinations of 2 factors [17]. This research was conducted to obtain a concept that can be used in improving the quality of production of fuel transportation tank products. to solve quality problems using the Design of Experiments (DoE) approach of complete factorial design 2^k.

1.1. Problem Formulation

The problem formulation based on the background of the problem is what are the factors that affect the quality of fuel transportation tanks and how to improve the quality process of fuel transportation tanks?

1.2. Research Objectives

The objectives of the research conducted are to determine the factors that affect the quality process of fuel transportation tanks and to find out how to improve the quality process of fuel transportation tanks.

2. Methods

The research was conducted at PT Sejahtera Mandiri Pekanbaru and focused on the welding process on the fuel transportation tank. This research used a quantitative approach namely measuring the relationship between variables in the problem being solved is causal, so there are independent variables and dependent variables, which will later be known the causal relationship of these variables [18]. The study used the full factorial 2^k Design of Experiment method. Primary data was collected through observations and interviews, while secondary data was obtained from production records for the 2019-2024 period. ANOVA analysis for factor level optimization was conducted in data processing.

It describes the step-by-step process of conducting DoE and also has several guidelines for implementation, including [19]:

1. Set Objectives Based on the Problem being Investigated To find out the types of defects that will be prioritized in analyzing the problem, data processing is necessary.

2. Response Variable Description So that the predicted results of the experiments are based on the set objectives.

3. Deciding on Factors and Levels Determination of independent variables can cause changes in the response variable. Able to identify factors that affect the response variable, using a fishbone diagram.

4. Confirming the Experiment Design Type Screening design is necessary for identification of meaningful factors or for optimization of the response function of the factor to be planned and determination of the number of test samples.

5. Analyzing Data

6. The stage of analyzing data there is a statistical method used ANOVA.

2.1. Framework

The following are the two types of variables used in this study dependent and independent.

1. There are additional factors that can affect the value of the dependent variable [18]. The focus of this research is on the following variables:
   a. Quality is the quality that can provide satisfaction to users or consumers when using these goods or services [20]. Quality defect level (porosity, undercut and crack) is the dependent variable.
2. Independent factors can have a positive and negative influence on the dependent variable [18]. The independent variables in this study are:
   a. Operator: The competition will be tough, but certified welders will have an edge. The benefits of obtaining welder certification are many, and they include being the go-to person for consumers, having confidence in your company, increasing market share, and handling large projects with ease [8].
   b. Ambient Air: Low tensile strength is caused by the temperature of the unheated electrode or the ambient temperature. Unheated electrodes tend to result in more defects [6].
   c. Holding Ovens High tensile strength is one of the results of the heated electrode temperature [6]. Electrode oven temperature (260°C to 425°C) for 1 hour.

The pattern of relationships between variables in the conceptual framework in this study can be seen in Figure 1.

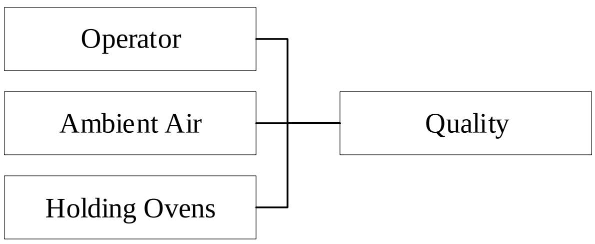


Figure 1. Conceptual Framework

Defect rate formulation can be calculated by the formula

$$\text{Defect Rate (\%)} = \frac{\text{Number of Defects}}{\text{Total Proution}} \text{ x } 100 \quad (1)$$

This enables the identification of defects in the production process by processing the findings. The procedure of determining the cause of the defects found is the next step which is by applying the Design of Experiment full factorial 2^k approach to determine the reason behind the occurrence of defects.

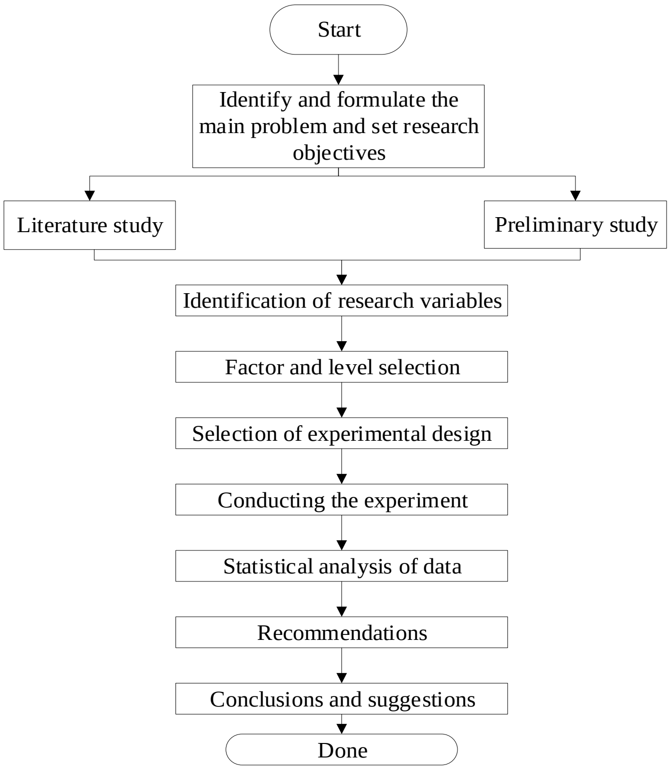


Figure 2. Research Procedure

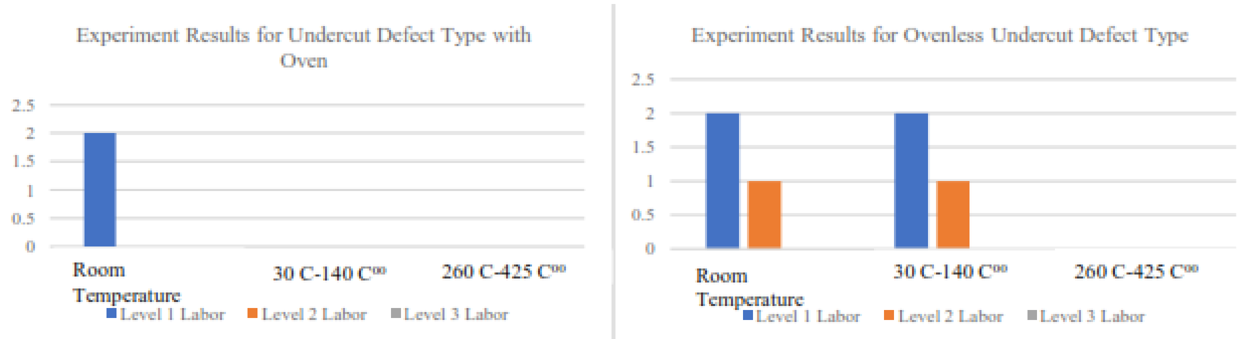
3. Results and Discussion

3.1. Experiment Result Output

The result that will come out of each experiment is the number of defects and this number will be divided according to the type of defect that exists. What will then be entered into the Minitab 18 calculation is the probability of a successful part not being defective. If the number that comes out for thin defects is 2 operators out of 12 tested operators, then the probability of a successful part not being affected by defects is 2/12 which is 0.833. The number of samples for each experiment was 12 operators and the experiment was started during normal working hours in the morning until the afternoon.

3.1.1. Types of Undercut Defects

The following is the amount of data generated during the experiment for the undercut defect type.



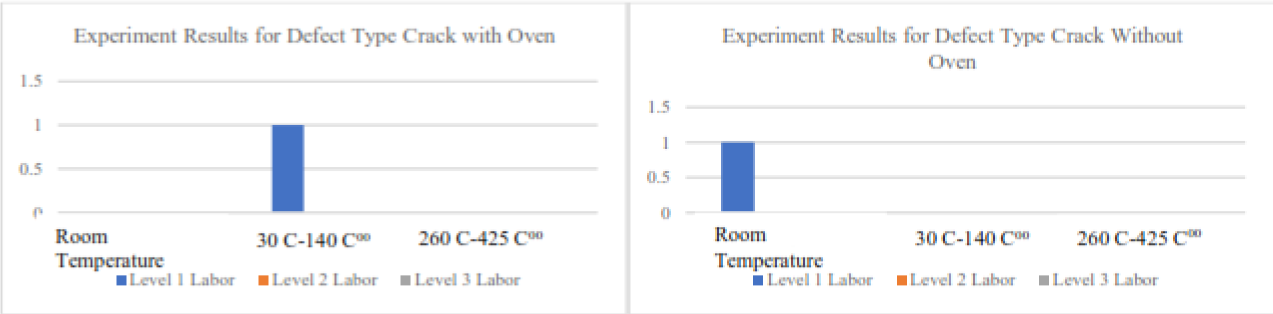
(a) (b)

Figure 3. (a) Experiment Results with Oven (b) Experiment Results Without Oven

Both graphs show a comparison of experimental results for undercut defects with and without the use of ovens at various temperature conditions and labor levels. In the graph with the oven, undercut defects are only found at room temperature and are limited to Level 1 labor with a value of 2, while at 30°C-140°C and 260°C-425°C undercut defects do not appear at all labor levels. This shows that the use of ovens can effectively eliminate undercut defects, especially with the right temperature setting. In contrast, on the graph without the oven, undercut defects occur more frequently, especially at room temperature and 30°C-140°C. This defect is dominant at Labor Level 1 (value of 2) and also appears at Labor Level 2 with a lower value (around 1). However, at 260°C-425°C, the undercut defect was not found at all labor levels, even though ovens were not used. This finding indicates that the use of ovens and optimal temperature control are critical in minimizing defects, especially when lower-skilled workers are involved.

3.1.2. Types of Crack Defects

The following is the amount of data generated during the experiment for the crack defect type.



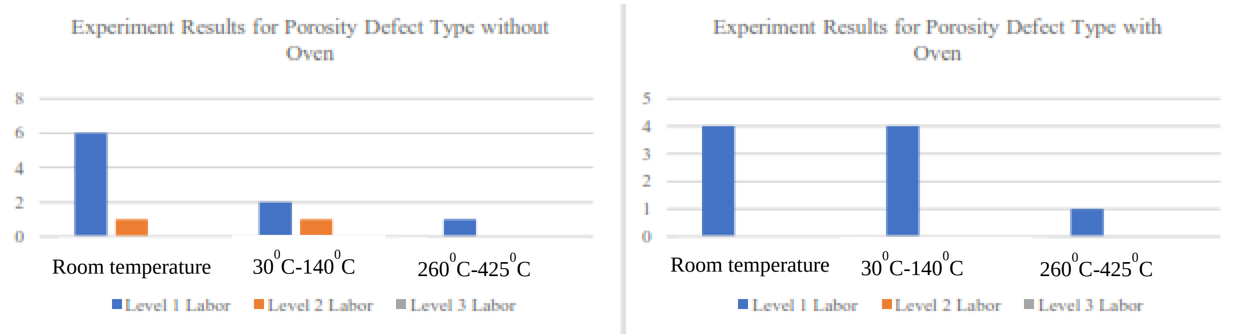
(a) (b)

Figure 4. (a) Experiment Results with Oven (b) Experiment Results Without Oven

Both graphs show a comparison of the experimental results for crack defect types with an oven and without the use of an oven at various temperature conditions and labor levels. In the graph with the oven, crack defects are only found at temperatures of 30°C-140°C at level 1 Labor, crack defects do not appear at all labor levels. This shows that the use of the oven can effectively eliminate crack defects, especially with the right temperature setting. In contrast, in the graph without the oven, crack defects appear at room temperature at level 1 labor. This finding indicates that operator level based on work experience is critical in minimizing defects, especially when lower-skilled workers are involved.

3.1.3. Defect Type Porosity

The following is the amount of data generated during the experiment for the porosity defect type.



(a) (b)

Figure 5. (a) Experimental Results without Oven (b) Experimental Results with Oven

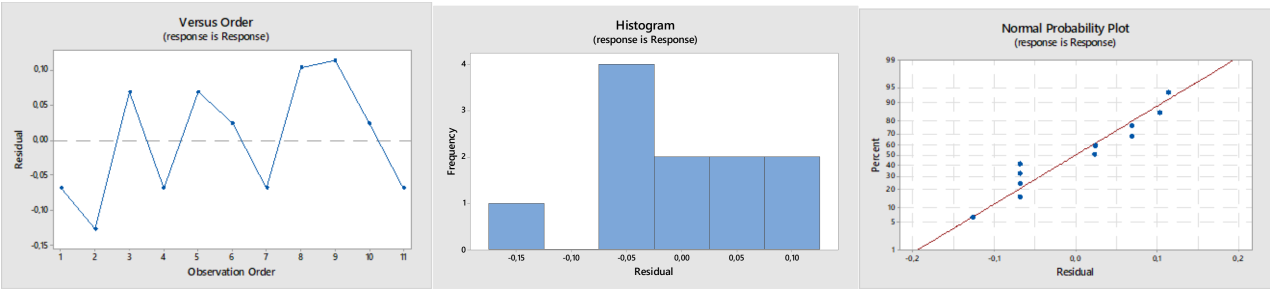
Both graphs show a comparison of experimental results for porosity defect types with and without the use of ovens at various temperature conditions and labor levels. In the graph without the oven, porosity defects are found at all temperatures and at labor levels 1 and 2, indicating that the use of the oven can effectively eliminate porosity defects, especially with proper temperature settings. In contrast, in the graph with the oven, porosity defects decreased, but these defects were found at all temperatures and only at labor level 1. This certainly indicates that the use and working of the welding process by operators requires skill.

3.2. Discussion

Based on the analysis using Minitab 18, the hypothesis results show significance if the p-value is smaller than alpha (0.05), which means accepting H_1 and there is a significant effect, whereas if the p value is greater than alpha, then H_0 is accepted, indicating no significant effect. In addition, the test also considers the F value, where H_1 is accepted if the F value falls outside the range of 3.2 to 5.6. The validity of the experiment is tested using the normal probability plot of residuals, where good data meets the assumption of normality, indicated by residual data that is close to the normal plot line and a bell-shaped histogram. If the histogram is not perfect or there are separated bars, this indicates the presence of outlier data, i.e. values that are much larger or smaller than the rest of the data. The scatter diagram of the residuals against the order of observations shows how random and distributed the data is, the more random and closer to zero, the better the distribution of the data, and indicates that the order of observations does not affect the experiment.

3.2.1. Undercut Defect Type Analysis

Residual Graph for Undercut Defect can be seen in the Figure 6.



(a) (b) (c)

Figure 6. (a) Versus Order (b) Histogram (c) Normal Probability Plot

The normal probability graph shows that the residual data is normally distributed. However, the histogram shows that there are data under the outliers. This also affects the experimental results which prove that no factor has a significant effect.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Termostate	1	0,03781	0,037812	3,83	0,091
Sertifikasi	2	0,04513	0,022566	2,28	0,172
Error	7	0,06913	0,009876		
Lack-of-Fit	1	0,03781	0,037813	7,24	0,036
Pure Error	6	0,03132	0,005219		
Total	10	0,15207			

Figure 7. Analysis of Variance for Undercut Defects

Based on Figure 7, it is known that certification has a P-Value of 0.091 for thermostat and 0.172 for certification. While the F-Value is 3.83 for thermostat and 2.28 for certification.

Analysis of the Effect of Factors and their Interactions, based on the residual normality test, the data is spread quite normally because the residual data is close to the normal line. After analyzing the variance, no significant factors were found to affect the number of defects. Based on the results found, the P-Value > 0.05 in the certification process, this indicates that no influencing factors were found because the value is above the desired alpha value for the occurrence of undercut defects. This indicates that for this type of undercut defect, the factors tested have no influence on it. The F value is also outside the bounds of other possibilities as the cause of the occurrence of this type of defect could be due to the quality of the material used being outdated or not in accordance with predetermined requirements. This means accepting H_0 that there is no significant effect on the defect rate.

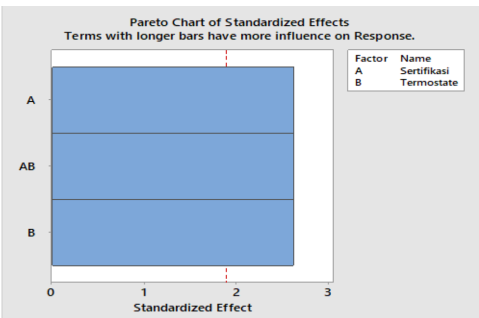
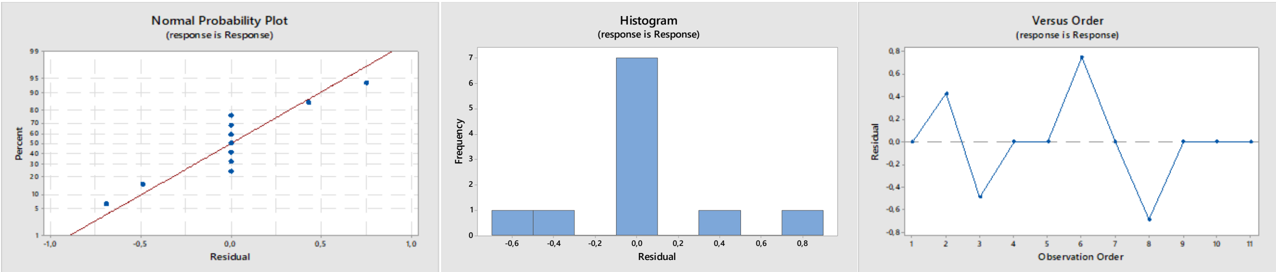


Figure 8. Pareto Graph of the Influence Level of Each Factor on Undercut Defects

This type of defect can also be caused by other processing because there are several other processes that are carried out manually by the operator, namely when fitting and bending, this aims to position the plate before welding.

3.2.2. Crack Defect Type Analysis

Residual Graph for Crack Defect in Figure 9 plots the residual data against the experimental model.



(a) (b) (c)

Figure 9. (a) Versus Order (b) Histogram (c) Normal Probability Plot of Crack Defect analysis

The normal probability graph shows that the residual data is normally distributed. However, the histogram shows that there are data under the outliers. This also affects the experimental results which prove that none of the factors have a significant effect.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sertifikasi	2	1,21189	0,60595	5,53	0,036
Termostate	1	0,69620	0,69620	6,35	0,040
Error	7	0,76740	0,10963		
Lack-of-Fit	1	0,69620	0,69620	58,67	0,000
Pure Error	6	0,07120	0,01187		
Total	10	2,67549			

Figure 10. Analysis of Variance for Crack Defects

Based on Figure 10, it is known that the P-Value is 0.036 for certification and 0.040 for thermostat. While the F-Value is 5.53 for certification and 6.35 for thermostat.

Factor Effect and Interaction Analysis, based on the residual normality test, the data is spread quite normally because the residual data is close to the normal line. After analyzing the variance, no significant factors were found that affect the number of defects. Based on the results found, the P-Value < 0.05, the discovery of influencing factors because the value is above the desired alpha value. This indicates that for the crack defect type, the factors tested have no influence on it. The F-Value is also outside the limits of other possibilities as the cause of this type of defect could be due to the quality of the material used being out of date or not in accordance with the requirements set by the company. This means accepting H_1 that there is a significant influence on the defect rate.

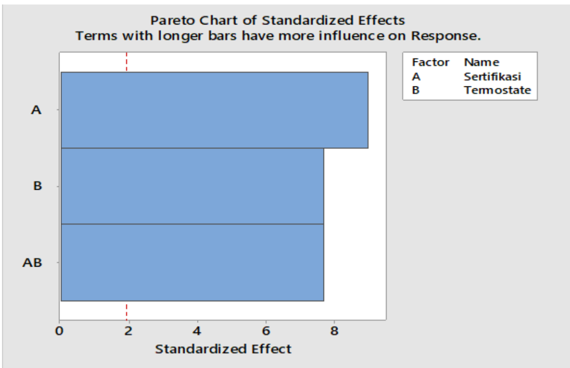
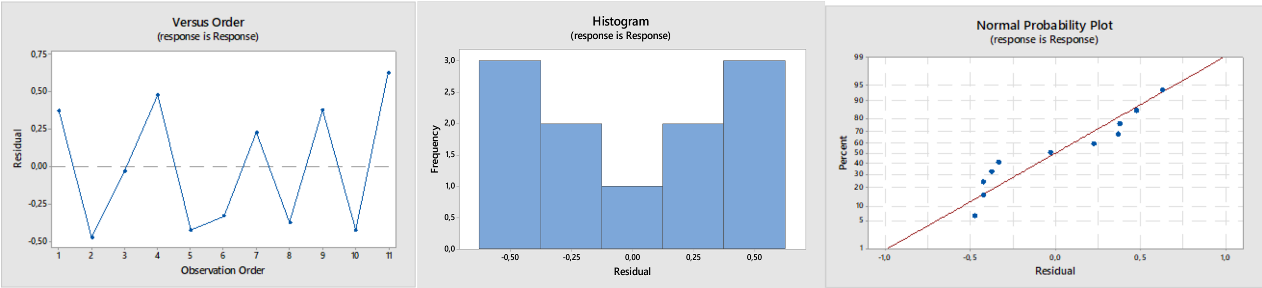


Figure 11. Pareto Graph of the Influence Level of Each Factor on Defect Crack

This type of defect can also be caused by several other processes carried out manually by the operator, namely when fitting and bending, this aims to position the plate before welding.

3.2.3. Porosity Defect Type Analysis

Residual Graph for Porosity Defect will illustrate the residual data against the experimental model.



(a) (b) (c)

Figure 12. (a) Versus Order (b) Histogram (c) Normal Probability Plot of Porosity Defect analysis

The normal probability graph shows that the residual data is normally distributed. However, the histogram shows that there are data under the outliers. This also affects the experimental results which prove that there are factors that have a significant effect.

Factor Effect and Interaction Analysis, based on the residual normality test, the data is spread quite normally because the residual data is close to the normal line. After analyzing the variance, no significant factors were found to affect the number of defects. Based on the results found the P-Value value <0.05. This is a factor in influencing the number of defects because the value is above the desired alpha value. This shows that for the porosity defect type, the factors tested have no influence on it. The F value is also within the limits of other possibilities as the cause of this type of defect could be due to the quality of the material used being out of date or not in accordance with predetermined requirements. This means accepting H_1 that there is a significant influence on the defect rate.

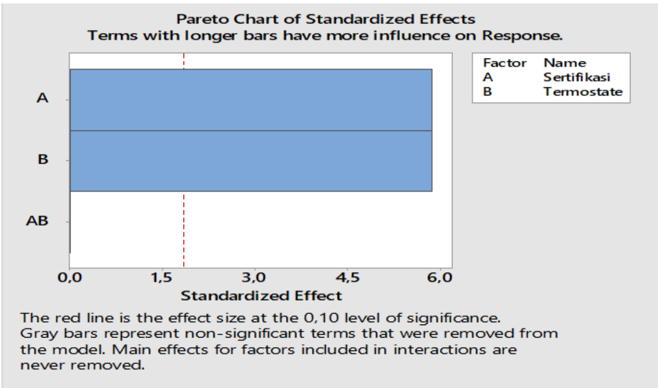


Figure 13. Pareto Graph of the Influence Level of Each Factor on Porosity Defects

This type of defect can also be caused by several other processes carried out manually by the operator, namely when fitting and bending, this aims to position the plate before welding.

Analysis of Variance

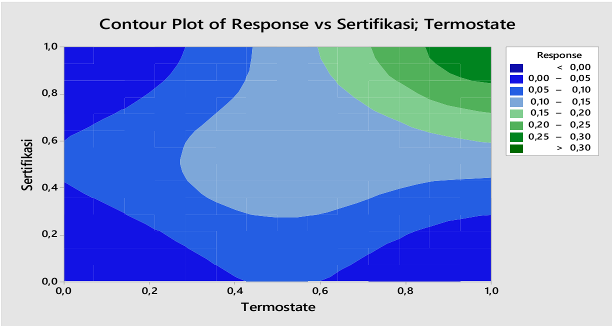
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Termostate	1	1,44500	1,44500	30,04	0,001
Sertifikasi	2	1,44561	0,72280	15,03	0,003
Error	7	0,33667	0,04810		
Lack-of-Fit	1	0,00000	0,00000	0,00	1,000
Pure Error	6	0,33667	0,05611		
Total	10	3,22727			

Figure 14. Analysis of Variance for Porosity defects

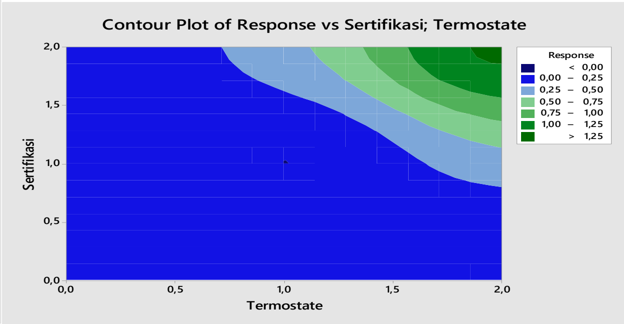
Based on Figure 14, it is known that the P-Value is 0.001 for thermostat and 0.003 for certification Meanwhile, the F-Value is 30.04 for thermostat and 15.03 for certification.

3.2.4. Optimal Combination for Improvement

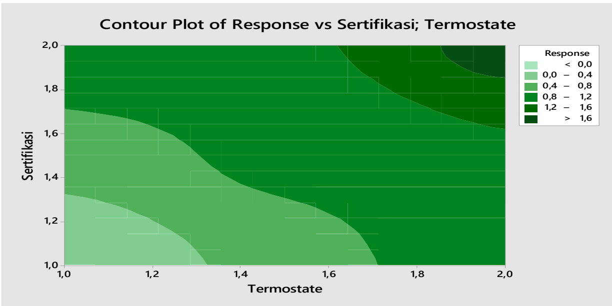
After knowing the factors that affect the level of defects that occur, the next step is to find the right combination to reduce the level of defects that exist. Based on the experiments that have been carried out, there will only be three combinations of improvement experiments based on the significance of the factors that have been found, namely for undercut, crack and porosity defects.



(a)



(b)



(c)

Figure 15. (a) Counter Plot of Undercut Defects (b) Counter Plot of Crack Defects (c) Counter Plot of Porosity Defects

As a result of the significance, the interaction factor that significantly influences is between skill and electrode oven. Figure 15 (a) shows the area that predicts the possibility that will be achieved with the combination of skills and electrodes there is only one, namely with no experience but has a certification and uses an electrode oven to maintain the temperature on the electrode. This will certainly affect the travel speed because it has enough training experience to do a good job. Based on the significance results, the interaction factor that significantly affects is between skill and electrode oven. Figure 15 (b) shows the area that predicts the possibility that will be achieved with a combination of skills and electrodes there is only one, namely with no experience but has a certification and uses an electrode oven to maintain the temperature on the electrode. This will certainly affect the travel speed because it has enough training experience to do a good job. Based on the significant results, the interaction factor that significantly affects is between skill and electrode oven. Figure 15 (c) shows the area that predicts the possibility that will be achieved with the combination of skills and electrodes there is only one, namely with no experience but has a certification and uses an electrode oven to maintain the temperature on the electrode. This will certainly affect the travel speed because it has enough training experience to be able to do a good job.

3.2.5. Defect Rate Analysis

The x-axis indicates a specific category or sequence (usually year, but needs to be verified). From 1 to 6, there are six data points. The y-axis, which ranges from 0 to 7%, displays the failure rate as a percentage (%). The defect rate before the study (orange line) fluctuated, peaking in the fourth stage with a defect rate of about 4.8%. From the first low point of 1.3% (1), it jumped to 2.4% at the second point, then dropped to 1.4% before rising once again to 4.8%. The failure rate dropped dramatically to 0.3% at the final point (6) after the peak. Defect rate data after the study (gray line). Higher defects are seen at all starting points compared to the results before the study. The highest defect rate is about 5-6% at the 4th point, which reflects a much larger defect rate than before the study at the same position. A consistent decrease in defect rate occurred to a low value at the last position, indicating successful defect reduction.

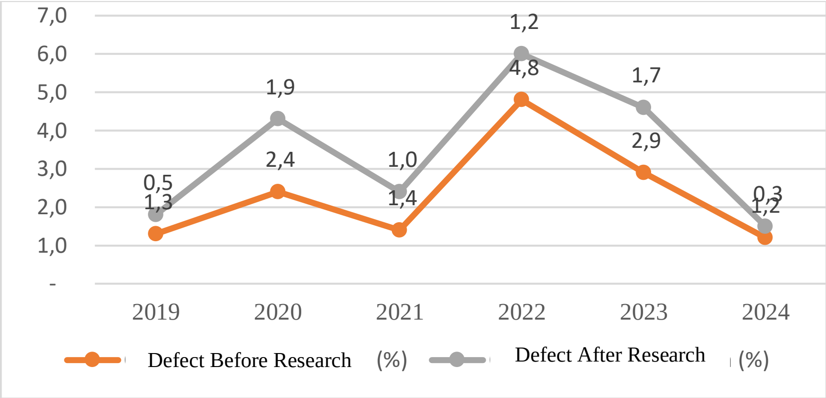


Figure 16. Defect Rate

Comparing Before and After Research: Starting Point (Position 1): After the study, the damage rate was 0.5% lower than before the study (1.3%). This shows a greater decrease until the end point, after having increased in the second position. The efficiency of the measures taken is shown by the more stable and decreasing shape of the post-study graph compared to the pre-study defect line. After the study, the defect rate fluctuated at each stage. The defect rate was 0.5% at the first point, which corresponds to the first period, most likely 2019. The defect rate was 1.0% at the second point. The defect rate decreased to 0.3% at the third point. The defect rate was 0.8% at the fourth point. So, the average defect rate after research is 0,65%.

3.2.6. Proposed Improvements

In an effort to improve the quality of welding results and work safety at PT Sejahtera Mandiri Pekanbaru, researchers have developed a new Standard Operational Procedure (SOP) for welding that can be applied and can reduce product defects so that product quality increases. This Standard Operational Procedure (SOP) details the welding procedures, from equipment preparation to equipment cleaning after work.

4. Conclusion

As a result of testing, several factors were found to affect the quality of fuel transportation tanks. Several types of defects such as undercut, crack, and porosity have different contributions to product quality. The porosity defect has the largest influence with a P-value of 0.001, followed by the crack defect with a P value of 0.040, while the undercut defect has a P-value of 0.091 so its contribution is smaller. The operator certification factor does not directly cause these defects, as seen from the P-Value of undercut defects of 0.172, Crack defects of 0.036, and porosity defects of 0.003. This study shows that certified operators have a significant influence on the quality of test results by producing products that have minimal defects. In contrast, non-certified operators tend to produce products with various types of defects due to lack of experience and absence of adequate work guidance. Other factors such as oven usage, temperature settings, and skills also prove to be very important in minimizing defects. Operator certification is therefore one of the best solutions to improve the quality of production output. Training and certification are necessary to ensure operators have sufficient expertise in the welding process and can minimize potential defects due to technical errors or lack of work experience.

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