

Porosity Scale Evaluation of Shielded Metal Arc Welding (SMAW) Specimen using Dye Penetrant Testing

Wan Mohammad Hafiz Wan Mohd Nazre¹, Sri Yulis M Amin^{1*}, Muhamad Nurul Fitri Kamisan², Muhammad Shazwan Khir Mohd Rizal¹

¹ Centre of NDT Training and Calibration (CENDTEC), Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, MALAYSIA

² Matech Engineering & Construction Sdn Bhd, Taman Mutiara Rini, 81300, Skudai, Johor, MALAYSIA

*Corresponding Author: yulis@uthm.edu.my

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Abstract

Non-destructive testing (NDT) denotes a collection of non-invasive inspection techniques employed to evaluate the properties of materials, components, and entire process units. NDT techniques are applicable for several types of inspections. Welds are among the most often inspected components of industrial assets. Inspectors can determine the robustness of a weld or identify any defects that may compromise its integrity with non-destructive weld testing apparatus. Welding is a crucial procedure in the metal fabrication sector. This research used Dye Penetrant Testing (DPT), a non-destructive testing technique, to examine the welding. This study aims to examine defects in Shielded Metal Arc Welding (SMAW) via Dye Penetrant Testing (DPT) and to optimize SMAW parameters for improved results in accordance with American Society of Mechanical Engineers (ASME) standards. The study identified two types of defects: porosity and cracks; however, porosity was selected for analysis. The Taguchi Method served as the optimization technique for welding parameters. The design summary employed the L9 orthogonal array, considering two factors: the welding current and the thickness of the mild steel plate sample. The signal-to-noise ratios were configured to prioritize lower values, as the objective is to achieve the minimum output to minimize welding defects. The link between porosity, welding current, and sample thickness indicates that a higher welding current applied to a thicker sample result in fewer porosity flaws. Applying the highest welding current to the sample with lower thickness will result in more porosity flaws. The optimal parameters for minimizing porosity in the welded specimen are a current of 100 A and a thickness of 6 mm.

1. Introduction

The dye penetrant test (DPT), also known as the liquid penetrant test, is frequently used to detect surface discontinuities such as cracks, fractures, porosity, grinding defects, partial fusion, and joint faults [1]. The process of dye penetrant testing involves spraying a penetrating liquid, typically a colored or fluorescent dye, onto the surface under evaluation. The surface is cleansed after allowing the penetrant to act for a few minutes and then

either left or coated with a dye-absorbing substance. Any break eventually seeps the liquid out, which is detectable as a darkening of the dye-absorbing layer or under ultraviolet light [2].

Welding is the process of fusing materials together inside the welding zone using force, heat, and/or filler metal [3]. Welding is most commonly associated with metals and thermoplastics, but it can also be used on wood [4]. The most important factors determining the quality, productivity, and cost of welding joints in this process are welding parameters [5]. The shielded metal arc welding method requires the selection of appropriate parameters based on technical facts in order to generate high-quality welds [6].

SMAW is a manual welding technique that is formed using a metal rod covered in flux, hence the term "stick." After passing through the rod, electricity strikes the base metal. The gas shield is created by flux, making this weld adaptable. It melts a consumable electrode and base metal using the arc's heat [7]. The shielded metal arc welding (SMAW) process results in the coalescence of metals by maintaining heat from an electric arc between the tip of a consumable electrode and the surface of the base material in the welding joint. SMAW is often used to weld stainless steel, carbon steel, alloy steel, and cast steel [8].

Welding defects are irregularities, discontinuities, blemishes, or inconsistencies in the weld surface of welded pieces. These defects come from a variety of places. Poor weld design, ineffective welding methods, and the use of incompatible materials typically cause faults. In addition, a lack of process expertise, poor craftsmanship, and insufficient welder training can all contribute to these flaws. Critical welding quality evaluation can control welding defects to acceptable levels [9]. Welding defects are flaws created in the weld metal as a result of a poor welding procedure or erroneous welding patterns, for example. The flaw could be different from the desired shape, size, and quality of the weld bead. There are two types of welding defects: external and internal problems [10].

2. Materials and Methods

2.1 Material Preparation

A mild steel plate with dimensions of 100 mm x 50 mm was prepared as a material for welding specimens. A total amount of 18 mild steel plates that have different thicknesses were welded using the butt joint method before being tested with dye penetrant testing. The thickness of the plate that has been used was 4 mm, 5 mm, and 6 mm.

2.2 Procedure

The experiment started with the welding process. The SMAW process starts with a constant current power supply (DC) as the power source. The electrodes utilized in this experiment were E-6013. Nine samples were examined under varying parameters. The parameters employed in this experiment were the thickness of the mild steel plate and the welding current. Upon the application of the specified parameters for welding the specimen material, the resultant welded sample will undergo evaluation using Dye Penetration Testing (DPT). This experiment utilized the ASME B31.1 standard as a reference.

The DPT process commenced with the cleansing phase. Components must be free of dirt, rust, scale, oil, and grease to facilitate reliable inspection. Subsequently, the penetrant was applied to the sample surface. Following sufficient time for penetration, excess penetrant is removed, and a developer is subsequently applied. The developer efficiently extracts the dye penetrant from the defects and deposits it onto the surfaces, thereby making the defects visible. The bleed-out is the term for this procedure. The bleed-out distinctly indicates the specimen's location, characteristics, and direction of defects.

2.3 Weld Defect Characterization

A defect is a breach of a material's typical physical structure that significantly alters its properties. A simple alteration in properties does not induce discontinuity. Welding flaws should only be considered if they are above the tolerance threshold. In this section, the defective outcome from the welding specimen that will be generated will be decided. The project's results depend on dye penetration testing data, as DPT identifies defects in the welding specimen. Porosity and cracks are defects assessed during dye penetrant testing. Crack defects are determined by measuring the crack's length. Utilize the subsequent formula to compute porosity:

$$\frac{\text{Area of defect}}{\text{Area of welding}} \times 100 \quad (1)$$

2.4 Optimization by Taguchi Method

The Taguchi method was employed to optimize the welding parameters of this experiment with Minitab. The design summary included the L9 orthogonal array, taking into account two factors. Taguchi analysis was

conducted using Minitab to examine the relationship between porosity scale, current, and thickness. The signal-to-noise ratio was configured to prioritize lower values, as the objective is to get the smallest output to minimize welding defects. The highest point of the signal-to-noise ratios graph will be selected as the optimized parameter in this experiment.

3. Results and Discussion

The results and data obtained from the experiment are discussed to support the objectives of the current research. Testing reveals that welding defects are visible to the naked eye when a red color appears on the welding surface. When the data is collected, the graph will be plotted to compare between parameters. Porosity has been selected for analysis because this defect is present in all samples compared to a crack that is present in one sample only. Table 1 shows the result of the porosity scale after the calculation has been made in all samples.

Table 1 *Experimental data*

Sample	Current (A)	Thickness (mm)	Porosity Scale (%)
Sample 1	60	4	8
Sample 2	60	5	13
Sample 3	60	6	18
Sample 4	80	4	13
Sample 5	80	5	7
Sample 6	80	6	10
Sample 7	100	4	17
Sample 8	100	5	13
Sample 9	100	6	3

For 60 A current, the porosity scale for a 4 mm thick mild steel sample was 8%, while the porosity scales for 5 mm and 6 mm thick samples were 13% and 18%, respectively. The application of the current to the 4 mm thick mild steel plate was effective, resulting in a minimal defect. The porosity scale of the 5 mm and 6 mm thickness samples is higher than that of the 4 mm thickness sample. This is because the 60 A current is insufficient for the 5 mm and 6 mm thickness samples, leading to an increase in porosity defects in the weld. The porosity scale for the 80 A current was minimal in the 5 mm thick sample, at 7%. The porosity measurements for samples with thicknesses of 4 mm and 6 mm were 13% and 10%, respectively. The 80 A current for the 5 mm thick sample is optimal due to its minimal defects. For the 100 A current, the porosity scale for the 6 mm thick sample was the lowest at 3%. The porosity measurements for samples with thicknesses of 4 mm and 5 mm were 17% and 13%, respectively. The 100 A current was optimal for a 6 mm thick sample, as it resulted in the fewest defects. This investigation demonstrates that the welding current and sample thickness have a significant impact on weld defects. Table 1 shows that sample 3, with a current of 60 A and a sample thickness of 6 mm, exhibited the maximum porosity. The current is insufficient for a 6 mm sample thickness, resulting in the largest porosity defect in that sample. Sample 9 exhibited the lowest porosity, utilizing a 100 A current and a sample thickness of 6 mm. The optimal current for a sample thickness of 6 mm is 100 A.

Figure 1 shows that the 60 A current exhibits the lowest porosity scale compared to the 80 A and 100 A currents in 4 mm thick mild steel plates. A current of 60 A is optimal for welding a 4 mm thick sample, as it yields the lowest porosity scale compared to 80 A and 100 A. A 60 A current is more appropriate for a 4 mm thick sample than 80 A, whereas 100 A is excessively high for this thickness. Figure 2 indicates that the sample with a thickness of 5 mm exhibits the lowest porosity level with an 80 A current. The graph exhibits an anomalous trend, as the 5 mm thickness sample performs better at 80 A than at 60 A or 100 A currents. The graph indicates that a 60 A current is insufficient, while a 100 A current is excessive for a sample with a thickness of 5 mm. Figure 3 illustrates that the sample with a thickness of 6 mm exhibits the lowest porosity level at a current of 100 A. The data indicates that a 100 A current is optimal for a 6 mm thick sample compared to other current levels. The graph is declining because the maximum current will yield a low porosity measurement in a 6 mm thick sample. Furthermore, the graph in Fig. 1 exhibits an upward trend, as the lowest current corresponds to the low porosity scale in a 4 mm thick sample. The correlation between welding current and sample thickness indicates that an increase in sample thickness necessitates a corresponding increase in welding current to achieve optimal weld quality. This is evidenced by the fact that the current suited for a 4 mm sample thickness is 60 A, whereas for a 5 mm thickness, the proper current is 80 A. Finally, for a sample thickness of 6 mm, the appropriate current is 100 A. The correlation between porosity, welding current, and sample thickness indicates that applying the maximum welding current to a thicker sample result in less porosity defects. Applying the maximum welding current to a thinner material will result in increased porosity defects.

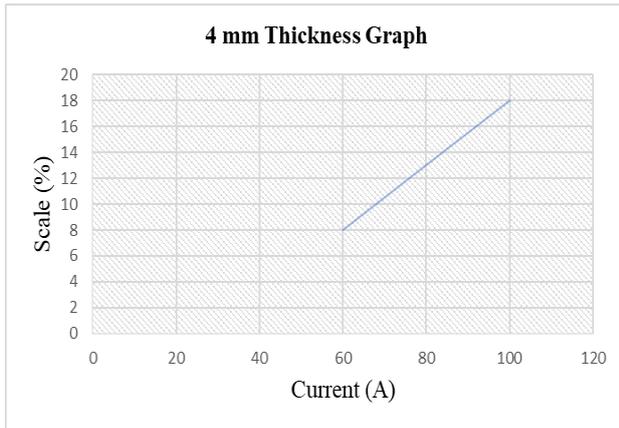


Fig. 1 4mm thickness graph

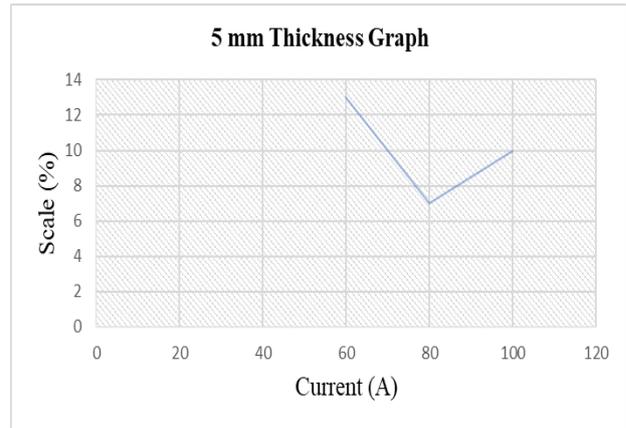


Fig. 2 5mm thickness graph

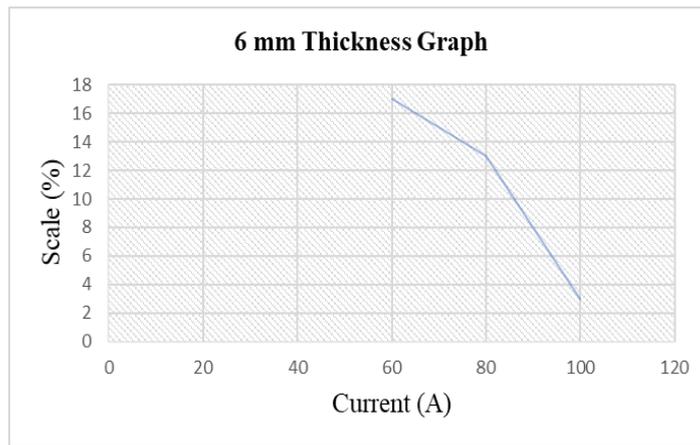


Fig. 3 6mm thickness graph

3.1 Optimization Method Using Taguchi Method

The Taguchi method was used as the optimization for the welding parameter of this experiment by using Minitab. The design summary involved the L9 orthogonal array, which was optimized using two factors. Table 2 displays the welding parameters at various levels.

Table 2 Welding parameters with different levels

Symbol	Welding Parameter	Level 1	Level 2	Level 3
A	Welding Current (A)	60	80	100
B	Thickness Mild Steel (mm)	4	5	6

Table 3 provides the rankings of each processing parameter. The thickness of mild steel plates is prioritized over the welding current. The thickness of the plate is the critical processing parameter in this welding procedure. Nonetheless, welding current may be the paramount processing component in the welding procedure.

Table 3 Response table for signal to noise ratios (smaller is better)

Level	Welding Current (A)	Thickness Mild Steel (mm)
1	-21.82	-21.65
2	-19.73	-20.49
3	-18.81	-18.22
Delta	3.01	3.43
Rank	2	1

Figure 4 illustrates a significant disparity in the mean SN ratios of the welding current and steel plate thickness. The graph indicates that the mean SN ratios rise as the thickness of the steel plate increases. The optimal parameters for minimizing porosity in the welded specimen are a current of 100A and a thickness of 6 mm. It is selected from the peak of the curve for signal-to-noise ratios.

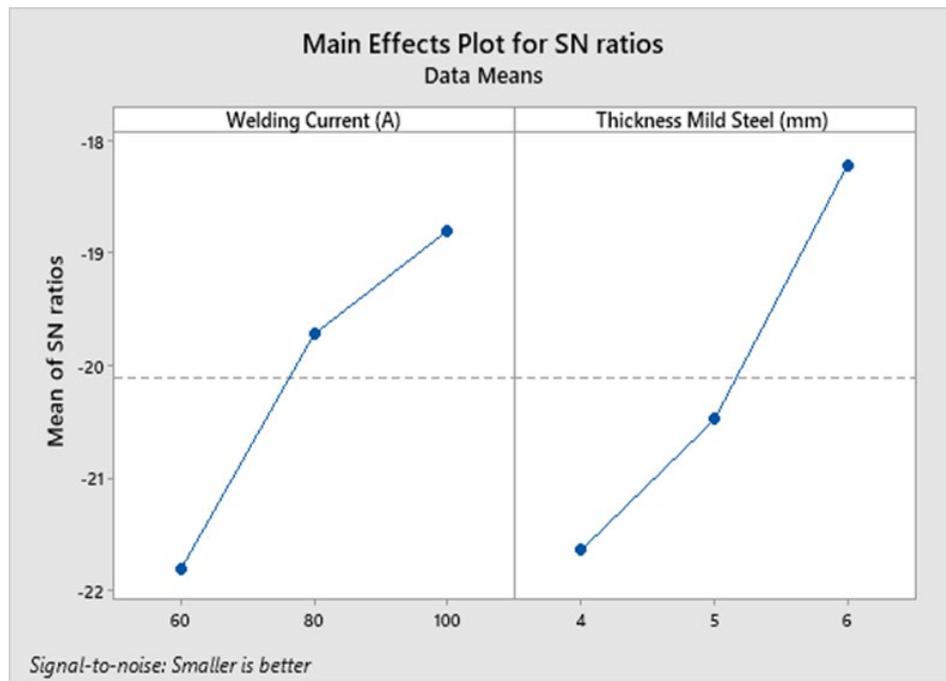


Fig. 4 Main effects plot for SN ratios graph

4. Conclusion

The objectives of this experiment project are to investigate defects in SMAW welding using dye penetrant testing, and to optimize the parameters of the SMAW welding process for improved output in accordance with ASME guidelines. This experiment allows us to analyze porosity defects, which are unique to all samples. Moreover, crack defects are only detectable in a single sample. Welding parameters are also important to determine the perfection of welding without any defects. Changing welding parameters, such as current and weld angle, in mild steel can significantly impact welding defects. These parameters must be properly adjusted so that we can properly weld a sample while minimizing the defects that may occur after the welding. It can be concluded that the optimized parameters in order to get the least amount of porosity in the welded specimen are 100A current and 6mm of thickness. This study has successfully achieved its objective.

This project can be enhanced in the future by the incorporation of certain improvements or recommendations. The first step is to compare the results of dye penetrant testing with those of two different non-destructive testing (NDT) methods: radiographic weld inspection and ultrasonic weld inspection. The next step is to get more detailed information by adding more parameters. Parameters such as electrode type, electrode size, welding speed, and welding angle may be incorporated. Furthermore, welding samples may be joined utilizing various connection configurations, including corner joints or tee joints. The sample's thickness is influenced by significant variations, such as 4 mm, 7 mm, and 10 mm, as minor differences in thickness impact only a limited number of factors.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** Wan Mohammad Hafiz Wan Mohd Nazre, Sri Yulis M Amin **data collection:** Wan Mohammad Hafiz Wan Mohd Nazre, Muhamad Nurul Fitri Kamisan **analysis and interpretation of results:** Wan Mohammad Hafiz Wan Mohd Nazre, Sri Yulis M Amin, **draft manuscript preparation:** Wan Mohammad Hafiz Wan Mohd Nazre, Sri Yulis M Amin, Muhammad Shazwan Khir Mohd Rizal. All authors reviewed the results and approved the final version of the manuscript.

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