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Analysis of Weld Defects in TIG Welding of St 37 Steel with Variations in Welding Current

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A R T I C L E I N F O

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A B S T R A C T

TIG (Tungsten Inert Gas) welding is a welding method widely used in the manufacturing industry because it produces high-quality joints, good precision, and low contamination levels. However, the quality of the weld is significantly influenced by the welding parameters, particularly the electric current used. This study aims to analyze the effect of varying TIG welding currents on weld defects in ST 37 steel using the Dye Penetrant Inspection (DPI) method. The current variations used were 80 A, 90 A, and 100 A. The results showed that the 80 A current produced the most defects, in the form of porosity and incomplete penetration, with a defect percentage of 50%. The 90 A current produced the best weld quality with a defect percentage of 16.67%, while the 100 A current produced defects in the form of undercuts and distortion, with a defect percentage of 33.33%. The heat input values obtained were 0.80 kJ/mm, 0.90 kJ/mm, and 1.00 kJ/mm, respectively. Based on the research results, it can be concluded that a current of 90 A is the most optimal welding parameter for TIG welding of ST 37 steel

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INTRODUCTION

Welding is the process of joining two or more pieces of metal using heat, resulting in a strong bond. It is crucial in modern industry, as welded joints are utilized in nearly all metal constructions; the quality of these joints largely determines the durability, strength, and safety of the structure. One popular welding method is TIG (Tungsten Inert Gas), also known as GTAW (Gas Tungsten Arc Welding). This method employs a non-consumable tungsten electrode and argon gas to shield the molten metal from the atmosphere. TIG welding offers several advantages, including high-quality weld results, good penetration, and clean joints.ST 37 steel is a type of low-carbon steel frequently used in construction, manufacturing, and machinery. Its weldability makes it a suitable material for welding research however, the quality of the resulting weld is significantly influenced by the welding current. If the welding current is too low, penetration is insufficient, potentially leading to defects. Conversely, excessive current can damage the metal. Therefore, research is needed to understand how varying the current affects the quality of TIG welds on ST 37 steel.While previous studies have examined the impact of welding parameters on weld joint quality in low-carbon steel, research specifically analyzing the relationship between TIG welding current variations, the percentage of weld defects, and heat input values for ST 37 steel remains relatively limited. Consequently, this study aims to investigate the effects of welding currents at 80 A, 90 A, and 100 A on weld quality and to determine the optimal current parameter that minimizes defects in TIG welding of ST 37 steel.

LITERATURE REVIEW

TIG Welding

TIG welding is an electric arc welding process that utilizes a non-consumable tungsten electrode and an inert shielding gas, such as argon or helium. The process occurs when an electric arc forms between the electrode and the workpiece, generating sufficient heat to melt both the base metal and the filler metal.

The advantages of TIG welding include:

- It produces high-quality joints.
- TIG welding generates minimal spatter, resulting in a cleaner and neater finish.
- The resulting weld bead has a superior, neater appearance.
- TIG welding is suitable for both thin and thick materials, offering great flexibility.
- It can be used on various types of metal, making it highly versatile and reliable for a wide range of welding applications.

ST 37 Steel

ST 37 steel is a type of steel with a relatively low carbon content, ranging from approximately 0.17% to 0.20%. It possesses a reasonably high tensile strength of around 370 MPa. ST 37 steel is widely used in various applications, such as steel construction, machine frame fabrication, tank manufacturing, and other industrial components. Due to its strength and broad utility, ST 37 steel is an excellent choice for many construction and industrial projects.

Heat Input

Heat input is the amount of thermal energy entering the material during welding. The equation for heat input is:

$$HI = \frac{(V \times I \times 60)}{1.000 \times S}$$

where:
V = Voltage (Volts)
I = Current (Amperes)
S = Welding speed (mm/min)

If the heat input is too low, penetration is incomplete. However, if the heat input is too high, it can cause distortion and changes in the microstructure.

Weld Defects

Weld defects are imperfections occurring in a weld joint that can reduce the quality and strength of the joint.

Commonly encountered types of defects:

1. Porosity
2. Incomplete Penetration
3. Undercut
4. Distortion
5. Slag Inclusion
6. Crack

Previous Research

This steel is chosen because it is relatively inexpensive, easy to form, and has good weldability, making it widely used in building construction, bridges, and machine components. In practice, however, the welding process does not always produce joints that are free of defects. Various types of weld defects such as porosity, undercut, incomplete fusion, incomplete penetration, slag inclusion, and others frequently occur and have the potential to significantly reduce the quality of the joint (Tiarawati, 2017; Pradana et al., 2023; Kosasih et al., 2020). According to research by Wijaya et al. (2024), the Dye Penetrant Inspection (DPI) method is effective for detecting surface defects—such as porosity, cracks, and undercut—in low-carbon steel weld joints. Based on these previous studies, it is evident that welding current parameters significantly influence weld joint quality. However, research regarding the optimization of TIG welding current for ST 37 steel using the DPI method still requires further study.

METHODOLOGY

Research Design

This study employed an experimental research method to investigate the effect of welding current variations on weld defects in Tungsten Inert Gas (TIG) welding of ST 37 steel. The independent variable was the welding current, while all other welding parameters were maintained constant to ensure that the observed changes in weld quality resulted only from current variation.

Materials and Equipment

The material used in this study was ST 37 low-carbon steel with a thickness of 5 mm. Welding was performed using a TIG welding machine with Direct Current Electrode Negative (DCEN) polarity. Argon gas with a purity of 99.99% was used as the shielding gas to prevent contamination during welding. A 2.4 mm tungsten electrode and ER70S-2 filler rod were employed throughout the experiment.

The main equipment included:

- TIG welding machine
- Argon gas cylinder and regulator
- TIG torch
- Tungsten electrode (2.4 mm)
- ER70S-2 filler rod
- Angle grinder
- Steel wire brush
- Vernier caliper
- Camera for documentation
- Personal Protective Equipment (PPE)

Experimental Variables

Independent Variable

The welding current was varied at three levels:

- 80 A
- 90 A
- 100 A

Dependent Variables

The observed responses included:

- Weld bead appearance
- Penetration quality
- Weld bead width
- Surface weld defects
- Number and type of welding defects

Controlled Variables

The following parameters were kept constant throughout the experiment:

Table 1. Controlled Variables

Parameter	***Vaule***
Base Material	*ST 37 Steel*
Plate Thickness	*5 mm*
Plate Thickness	*Butt Joint*
Groove Type	*Single V-Groove*
Electrode Diameter	*2.4 mm*
Filler Metal	*ER70S-2*
Shielding Gas	*Argon*
Gas Flow Rate	*10 L/min*
Polarity	*DCEN*
Welding Speed	*Constant*

Experimental Procedure
The experimental procedure consisted of the following steps:
1. The ST 37 steel plates were cut according to the specified dimensions.
2. The welding surfaces were cleaned using an angle grinder and steel brush to remove rust, oil, dust, and other contaminants.
3. The TIG welding machine was prepared by installing the tungsten electrode, connecting the argon gas cylinder, and adjusting the gas flow rate.
4. Welding was performed using three different welding currents: 80 A, 90 A, and 100 A.
5. Each welding condition was repeated three times to improve the reliability of the experimental data.
6. After welding, the specimens were allowed to cool naturally at room temperature.
7. The welded joints were visually inspected and examined using the Dye Penetrant Test (PT) to identify surface defects.
8. All observations were recorded and documented for further analysis.

Weld Defect Inspection
The quality of each welded specimen was evaluated through visual inspection followed by Dye Penetrant Testing (PT). The inspection focused on identifying common welding defects, including:
- Porosity
- Undercut
- Overlap
- Incomplete Penetration
- Underfill
- Excess Reinforcement
- Surface Cracks

The inspection results were classified according to the number and severity of defects observed on each specimen.

Data Analysis
The collected data were analyzed using descriptive quantitative analysis. The weld quality produced under each welding current was compared based on:
- Type of weld defects
- Number of weld defects
- Weld bead appearance
- Penetration characteristics

The results were presented in tables and graphs to illustrate the relationship between welding current and weld quality. The welding current that produced the minimum number of defects and the best weld appearance was considered the optimal welding parameter for ST 37 steel under the conditions of this study.

RESULTS

Visual Inspection Results

We did an inspection right after the welding process to see what the weld bead looked like. We checked a things, such as how uniform the weld bead was, how wide it was and if there were any defects on the surface that we could see. The visual inspection results show that the welding current has an effect, on what the weld bead looks like. We found out that the welding current really matters when it comes to the appearance of the weld bead.

Table 2. Visual Inspection Results

Welding Current (A)	Weld Bead Appearance	Penetration	Surface Defects	Surface Defects
80	Narrow and uneven	Low	Porosity, Incomplete Penetration	Undercut, Distortion
90	Smooth and uniform	Good	Minor Porosity	Very Good
100	Wide bead	Excessive	Undercut, Distortion	Fair

The weld produced using 80 A exhibited shallow penetration and an irregular bead profile. Increasing the current to 90 A significantly improved bead uniformity and penetration. At 100 A, although penetration increased, excessive heat caused undercut and distortion along the weld toe.

Dye Penetrant Inspection (DPI) Results

Dye Penetrant Inspection was conducted to identify surface discontinuities that were not easily visible during visual inspection.

Table 3. Weld Defects Detected by DPI

Welding Current (A)	**Porosity**	**Incomplete Penetration**	**Undercut**	**Distortion**	**Total Defects**
80	2	1	0	0	3
90	1	0	0	0	1
100	0	0	1	1	2

The inspection results demonstrate that specimens welded using 80 A contained the highest number of defects. In contrast, the specimen welded at 90 A contained only one minor surface defect, while welding at 100 A resulted in thermal-related defects such as undercut and distortion.

Percentage of Weld Defects

The percentage of weld defects was calculated based on the total number of detected defects relative to the total inspection observations.

Table 4. Percentage of Weld Defects

Welding Current (A)	**Number of Defects**	**Defect Percentage (%)**

80	3	50.00%
90	1	16.67%
100	2	33.33%

The lowest defect percentage was obtained at 90 A, indicating that this welding current produced the highest weld quality under the experimental conditions.

Heat Input Calculation

Heat input was determined using the welding parameters during the experiment.

Table 5. Heat Input Values

Welding Current (A)	**Voltage (V)**	**Welding Speed (mm/s)**	**Heat Input (kJ/mm)**
80	20	Constant	0.80
90	20	Constant	0.90
100	20	Constant	1.00

The increase in welding current resulted in a proportional increase in heat input. Higher heat input improved penetration but also increased the possibility of excessive melting and thermal defects.

Relationship Between Welding Current and Weld Defects

The experiments show that there is a connection between the welding current and the quality of the weld. When the welding current is low, like 80 A it does not get hot enough so the weld is not strong. Has holes in it.. When we increase the welding current to 90 A it gets just hot enough to melt the metal properly and the arc stays steady which means we get the fewest defects in the weld. On the hand when the welding current is too high like 100 A it gets too hot and causes problems like the metal getting melted away in some places and becoming distorted. Overall what we found out is that using a welding current of 90 A is the way to get a good balance between making the weld strong looking good and having the least number of defects when we do TIG welding on ST 37 steel given the conditions we used for this study. We think that the welding current of 90 A is the choice for TIG welding of ST 37 steel because it gives us the best results. The welding current is very important for the quality of the weld and 90 A is the welding current, for this type of welding.

DISCUSSION

The experimental results demonstrate that welding current is one of the most influential parameters affecting the quality of TIG-welded joints on ST 37 steel. Variations in welding current directly influence the heat input, which determines weld penetration, bead geometry, and the formation of welding defects. At a welding current of **80 A**, the heat input was insufficient to fully melt the base metal, resulting in shallow penetration and an unstable weld pool. Consequently, defects such as **incomplete penetration** and **porosity** were more frequently observed. The narrow weld bead also indicated that the generated heat was inadequate to produce a sound welded joint. These findings suggest that low welding current reduces fusion efficiency and increases the likelihood of discontinuities within the weld. When the welding current was increased to **90 A**, the weld quality improved significantly. The heat input was sufficient to achieve proper fusion between the base metal and filler metal while maintaining a stable weld pool. Visual inspection and dye penetrant testing indicated that this current produced the fewest surface defects. In addition, the weld bead exhibited a uniform appearance with consistent width and reinforcement, indicating that **90 A** provided the most balanced welding condition for the ST 37 steel specimens used in this study.

At **100 A**, the increased heat input enhanced weld penetration but also introduced excessive melting of the base metal. As a result, defects such as **undercut** and excessive bead width became more apparent. Excessive heat input may also increase the width of the heat-affected zone (HAZ), potentially affecting the mechanical properties of the welded joint. Therefore, although higher current improves penetration, it may reduce weld quality if not accompanied by appropriate control of welding speed and torch manipulation. The overall results indicate that welding current must be carefully selected according to the thickness and characteristics of the material. Excessively low current produces inadequate fusion, whereas excessively high current increases the risk of thermal defects. Under the experimental conditions applied in this study, a welding current of **90 A** provided the optimum balance between penetration, weld bead appearance, and minimum weld defects. These findings are consistent with previous welding studies, which report that an appropriate heat input is essential for producing high-quality welds. Proper selection of welding current contributes to stable arc characteristics, improved fusion, reduced defect formation, and enhanced overall welding performance. Therefore, optimizing welding current is a critical factor in achieving reliable TIG welding results on ST 37 steel.

CONCLUSIONS AND RECOMMENDATIONS

This study investigated the effect of welding current variations on weld defects in TIG welding of ST 37 steel. Based on the experimental results and discussion, it can be concluded that welding current has a significant influence on weld quality, penetration characteristics, and the occurrence of welding defects. The welding current of **80 A** produced insufficient heat input, resulting in shallow penetration and a higher occurrence of defects, particularly porosity and incomplete penetration. These defects indicate inadequate fusion between the base metal and the filler metal. Increasing the welding current to **90 A** produced the highest-quality welded joint. This current generated adequate heat input to achieve stable arc characteristics, proper penetration, uniform weld bead geometry, and the lowest number of weld defects. Therefore, 90 A was identified as the optimum welding current under the experimental conditions of this study.

At a welding current of **100 A**, the higher heat input improved penetration but also increased the possibility of thermal defects, such as undercut and excessive weld bead width. Excessive heat input may negatively affect the weld profile and enlarge the heat-affected zone (HAZ), potentially influencing the mechanical performance of the welded joint. Overall, the findings demonstrate that selecting an appropriate welding current is essential for producing sound TIG welds with minimal defects. Proper heat input contributes to improved weld appearance, stronger fusion, and reduced defect formation.

Recommendations

Based on the findings of this study, several recommendations are proposed. Welding operators should carefully select the welding current according to the thickness and type of the base material to achieve optimum weld quality. For ST 37 steel with a thickness of 5 mm under the conditions used in this study, a welding current of approximately **90 A** is recommended because it produced the best balance between penetration and weld quality. To improve welding performance, the welding process should be carried out with stable arc length, consistent welding speed, appropriate torch angle, and adequate shielding gas flow to minimize contamination and defect formation. Proper surface preparation before welding, including the removal of rust, oil, and dirt, is also essential to reduce the occurrence of porosity and other surface defects. Future investigations are recommended to evaluate the influence of welding current on mechanical properties such as tensile strength, hardness, impact toughness, and bending performance. Additional studies involving different welding parameters, materials, plate thicknesses, and advanced non-destructive testing techniques are expected to provide a more comprehensive understanding of TIG welding quality and process optimization.

FURTHER STUDY

Although this study successfully analyzed the influence of welding current on weld defects in TIG welding of ST 37 steel, several limitations remain and provide opportunities for future research. The present work focused only on three welding current levels (80 A, 90 A, and 100 A) under constant welding conditions. Therefore, the findings are limited to the selected material, plate thickness, and welding parameters used in this experiment. Future studies should investigate a wider range of welding parameters, including arc voltage, welding speed, shielding gas flow rate, electrode diameter, electrode tip angle, filler metal type, and groove geometry. The interaction between these parameters and welding current could provide a more comprehensive understanding of the TIG welding process and its influence on weld quality. Further research is also recommended to evaluate the mechanical properties of welded joints through tensile, hardness, impact, and bending tests. These tests would help establish the relationship between weld defects and the structural performance of welded components. In addition, metallographic examinations using optical microscopy, scanning electron microscopy (SEM), and energy-dispersive X-ray spectroscopy (EDS) are suggested to analyze the microstructure, grain growth, and heat-affected zone (HAZ) resulting from different welding conditions. The application of advanced non-destructive testing (NDT) methods, such as radiographic testing (RT), ultrasonic testing (UT), magnetic particle testing (MT), and phasedarray ultrasonic testing (PAUT), is recommended to improve the detection and characterization of both surface and internal weld defects. Comparing these techniques with visual inspection and dye penetrant testing would provide a more comprehensive evaluation of weld integrity. Future investigations may also consider different base materials, plate thicknesses, welding positions, and industrial applications to validate the applicability of the findings under practical manufacturing conditions. Furthermore, statistical optimization techniques such as Design of Experiments (DOE), Response Surface Methodology (RSM), and Analysis of Variance (ANOVA) can be employed to determine the optimum welding parameters with higher accuracy and confidence. The results of these future studies are expected to contribute to the development of optimized TIG welding procedures that improve weld quality, minimize defect formation, enhance mechanical performance, and increase the reliability of welded structures used in manufacturing, construction, and engineering industries.

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