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Analysis of Weld Defects and Their Solutions in Manual Welding of Carbon Steel

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ABSTRACT

Welding is one of the most commonly used metal joining processes in the manufacturing and construction industries. However, this process often results in defects in the weld joint, especially in manual welding of carbon steel, which can affect the quality and strength of the joint. This study aims to analyze the types of welding defects that occur in manual welding of carbon steel, identify their main causes, and provide technical solutions to minimize such defects. The methods used include visual inspection, penetrant testing (PT), and macrostructure examination of the welded joints. The results show that the most common defects found are porosity, undercut, incomplete fusion, and slag inclusion. The primary causes of these defects include improper welding parameter settings, inadequate cleanliness of the metal surface, and the skill level of the operator. As solutions, it is recommended to conduct regular operator training, adjust current and voltage according to the type of electrode used, and ensure proper surface preparation before welding. This study is expected to serve as a reference for industry practitioners in improving the quality of carbon steel weld joints

KEY WORDS: *Welding defects, manual welding, carbon steel, joint quality, porosity, undercut, incomplete fusion, slag inclusion..*

NOMENCLATURE

pH	potential of hydrogen
mm	millimeters
A	ampere

1.0 INTRODUCTION

1.1 Background

Welding is one of the most important processes in the field of engineering and fabrication, serving to join two or more metal parts into a single unified structure. In modern industry, welding technology plays a crucial role in supporting construction activities, heavy equipment assembly, steel structure fabrication, and the production of vehicles and ships. Among the various joining techniques available, welding is considered the most efficient method in terms of joint strength, production cost, and on-site application flexibility.

Carbon steel is one of the most commonly used metal materials in the industrial world due to its favorable mechanical properties, such as relatively high tensile strength, weldability, and cost-effectiveness compared to high-alloy steels or non-ferrous metals. Therefore, the selection of carbon steel as the primary material in many construction and manufacturing projects is a logical and economical choice. However, in the process of joining carbon steel, especially using manual welding methods, there are still several challenges that can affect the quality of the welded joints.

Manual welding, such as Shielded Metal Arc Welding (SMAW), remains widely used due to its simple equipment, portability, and relatively low power requirements. Nevertheless, the success of manual welding heavily depends on the skill and experience of the operator, as well as proper settings of process parameters such as current, voltage, welding speed, and electrode selection. Errors in any of these aspects can lead to various types of welding defects that directly impact the strength and integrity of the weld joint.

Welding defects are imperfections in the weld that may appear as porosity (gas bubbles), undercut (grooves along the weld toe), incomplete fusion (insufficient bonding between metal parts), slag inclusion (trapped slag within the weld), and various forms of cracks or shape deviations. The presence of these defects not only reduces the visual quality of the weld but also poses a risk of structural failure when components are subjected to heavy working conditions. This is especially dangerous in building structures or heavy equipment that rely on weld strength for load-bearing purposes.

In light of these issues, this study was conducted to analyze the various types of welding defects that occur in manual welding of carbon steel, identify their root causes, and formulate technical solutions that can be applied to minimize or even prevent such defects. The analysis was carried out through direct observation of weld results, non-destructive testing such as penetrant testing (PT), and evaluation of process parameters and operator skills. It is expected that the findings of this study will contribute to improving the quality of manual welding in the field, serve as a reference for welder training programs, and support the implementation of quality standards in the welding industry.

1.2 Problem Statement

Although manual welding is still widely used in various industrial applications due to its simplicity and flexibility, this process often results in weld joints that contain defects. In manual welding of carbon steel, various types of defects such as porosity, undercut, incomplete fusion, and slag inclusion are commonly found, which can reduce the strength of the joint and compromise structural reliability. These defects arise not only from improper welding parameters but also from insufficient operator skills, workplace conditions, and poor surface cleanliness prior to welding. To this day, many industry practitioners and small-scale workshops still lack a comprehensive understanding of the types of weld defects, their causes, and systematic prevention methods.

Therefore, the main problems addressed in this study are:

1. What are the most common types of defects that occur in manual welding of carbon steel?
2. What are the contributing factors that cause these defects during the manual welding process?
3. What technical and procedural solutions can be applied to minimize welding defects in carbon steel?

This research aims to answer these questions through visual analysis, non-destructive testing, and a review of field welding practices in order to provide practical contributions toward improving weld quality and structural safety.

1.3 Research Objectives

Manual welding of carbon steel remains a widely used method in both fabrication and repair of metal structures across various industrial sectors, primarily due to its ease of execution and adaptability to diverse working conditions. However, this technique is prone to various types of weld defects when not performed using proper procedures and techniques. These defects not only reduce the visual quality of the weld joint but can also have serious impacts on the mechanical strength and overall structural reliability.

With the growing demand for strong and durable metal joints, a deeper understanding of the characteristics of weld defects, their causes, and solutions for prevention is essential. Therefore, this study focuses on comprehensively examining the various aspects that contribute to the formation of defects in manual welding of carbon steel, as well as the corrective measures that can be implemented. Specifically, this research aims to:

1. Identify and classify the common types of weld defects that occur during manual welding of carbon steel.
2. Analyze the contributing factors to weld defects, both from technical aspects (such as current, voltage, welding speed, and type of electrode) and non-technical aspects (such as operator skill and working environment conditions).
3. Evaluate the quality of weld joints through visual and non-destructive testing methods to obtain accurate data on weld conditions.
4. Formulate effective technical and procedural solutions to minimize or prevent weld defects in manual welding of carbon steel.
5. Provide recommendations for welding process improvements that can be implemented by industry practitioners and welding personnel to enhance joint quality and structural safety.

By achieving these objectives, it is expected that the results of this study can serve as a reference for industries, training institutions, and technical education organizations in improving welding process quality and reducing the risk of structural failure due to weld defects.

1.4 Research Benefits

The study on the analysis of weld defects and their solutions in manual welding of carbon steel is expected to provide contributions not only in academic terms but also in practical and applicable aspects in the professional field. The benefits that can be gained from this research include:

1. The results of this study can serve as an additional reference for students, lecturers, and researchers focusing on welding engineering, materials technology, or manufacturing. Information on defect classification, technical causes, and repair methods enriches the literature and can serve as a basis for further research.
2. This research offers practical guidelines for technicians, welding operators, and industry practitioners in identifying and addressing common welding defects. By understanding the root causes, the welding process can be carried out with higher quality and reduced risk of failure.
3. Implementing the solutions derived from this research has the potential to reduce material waste, production time, and costs. Consequently, industries can improve work efficiency and minimize expenses due to rework or replacement of failed joints.
4. Better weld joint quality contributes to increased workplace safety and structural reliability, whether in construction projects or product manufacturing. This, in turn, supports the creation of safer work environments and more reliable products for public use.
5. For workshops or small industries that rely on manual welding as part of their production process, this research can serve as a technical guide that is easy to understand and implement. Even without sophisticated equipment, SMEs can still improve their weld quality and enhance the overall quality of their products.

With these benefits, it is hoped that this research will have a positive impact on various stakeholders involved directly or indirectly in the welding process—whether from an educational, industrial, or societal perspective.

2.0 LITERATURE REVIEW

2.1 Manual Welding

Manual welding is a metal joining process performed directly by the operator without the assistance of automated mechanisms. One of the most widely used methods in this

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category is Shielded Metal Arc Welding (SMAW), also commonly referred to as manual arc welding. In this process, a flux-coated metal electrode is used to create an electric arc between the electrode and the base metal. The heat from this arc melts both the electrode and the base metal, allowing fusion or bonding to occur. The flux coating on the electrode melts and produces a shielding gas as well as slag that covers the weld metal, protecting it from air contamination during cooling.

The main advantage of manual welding is its versatility in various welding positions (flat, vertical, overhead) and its simple, portable equipment, which makes it highly popular in building construction, metal structure repair, and small-to-medium-scale industries. In addition, SMAW can be applied to a wide range of metals including carbon steel, stainless steel, and cast iron, as long as the appropriate electrode is used.

However, the quality of the weld strongly depends on the operator's skill. Factors such as hand steadiness, understanding of welding parameters (such as current and electrode travel speed), and experience in reading weld conditions are key to achieving strong and reliable joints. Due to its manual nature, this method is more susceptible to welding defects such as porosity, undercut, and slag inclusion if not executed properly [1].

In the context of carbon steel welding, SMAW remains a preferred choice because carbon steel has good weldability and does not require special treatment like high-alloy metals. However, careful control of process parameters and proper electrode selection are still essential to ensure that the resulting weld meets the required strength and structural durability standards.

Manual welding is not only important as a production technique but also serves as the foundation for training professional welders. A deep understanding of its working principles, advantages, limitations, and potential defects is crucial for improving weld quality and ensuring safety in industrial applications.

2.2 Characteristics of Carbon Steel

Carbon steel is one of the most widely used metal materials in the industrial, construction, and manufacturing sectors due to its favorable mechanical properties, affordability, and ease of welding. In general, carbon steel is an alloy of iron (Fe) and carbon (C), with little or no significant addition of other alloying elements. The carbon content in steel greatly influences its mechanical and metallurgical properties, such as strength, ductility, hardness, and weldability.

Carbon steel is classified into three categories based on its carbon content:

1. **Low Carbon Steel**: Contains less than 0.3% carbon. This type is very easy to weld, has high ductility, and is widely used in the fabrication of lightweight structures, pipes, and automotive components.
2. **Medium Carbon Steel**: Contains between 0.3% and 0.6% carbon. This type of steel has higher strength and hardness compared to low carbon steel, but requires better control during the welding process to avoid cracking.
3. **High Carbon Steel**: Contains more than 0.6% carbon. This steel is very hard and strong, but has low ductility and is difficult to weld due to its tendency to crack during rapid cooling in the welding process.

In welding processes, the characteristics of carbon steel particularly its carbon content significantly affect the quality of the weld. Low carbon steel tends to be easier to weld without special treatment, while medium to high carbon steels often require preheating or post-weld heat treatment to reduce the risk of forming hard and brittle martensitic structures in the Heat Affected Zone (HAZ) [2].

Additionally, impurity levels such as sulfur, phosphorus, and oxygen in carbon steel can also influence the likelihood of defects such as porosity and hot cracking. Therefore, the selection of the appropriate type of carbon steel and an understanding of its metallurgical characteristics are crucial in welding planning and execution.

Due to its cost-effectiveness and ease of fabrication, carbon steel remains a primary material in a wide range of engineering applications, from building structures and machine frames to vehicle components. In the context of this study, understanding the characteristics of carbon steel forms the foundation for analyzing the causes of welding defects and formulating appropriate technical solutions in manual welding processes [3].

2.3 Types of Weld Defects

Weld defects are imperfections or abnormalities that occur in weld joints, either visually or structurally, which can reduce the mechanical, functional, and aesthetic quality of the weld. These defects may appear during the welding process or after the cooling phase. The presence of defects can decrease the strength of the joint, shorten the service life of the structure, and in certain cases, lead to total failure of the welded structure especially for components operating under high loads or vibration.

According to various welding standards such as AWS D1.1 and ISO 5817, weld defects are classified into several main types, including:

1. **Porosity**
   Porosity refers to small cavities or gas bubbles trapped within the weld metal. This defect usually occurs when gas does not escape before the metal solidifies. Common causes include contaminated surfaces (oily or rusty), moisture in the electrode, or poor welding technique. Porosity can reduce the strength and corrosion resistance of the weld joint.
2. **Undercut**
   Undercut is a groove or notch formed at the edge of the weld bead where the base metal melts but is not filled with weld metal. This defect is usually caused by excessive welding current, too high travel speed, or incorrect electrode angle. Undercuts can become structural weak points that may trigger cracking or joint failure.
3. **Incomplete Fusion**
   This defect occurs when the weld metal does not properly fuse with the base metal or between layers of weld metal. It can be caused by insufficient heat input, excessive travel speed, or unclean metal surfaces. Incomplete fusion weakens the bond between metals and may cause the joint to fail under tensile or shear loads.
4. **Slag Inclusion**
   Slag inclusion refers to the entrapment of slag (flux residue) within the weld metal. This can happen if slag

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from the previous layer is not properly cleaned before the next layer is applied, or due to poor welding technique. Slag inclusions interfere with metal continuity and can be the starting point of cracks.

5. **Cracks**
   Cracks can occur during or after welding and are generally categorized as hot cracks or cold cracks. Causes may include residual stresses, brittle microstructures formed by rapid cooling, or incompatibility between base material and filler material. Cracks are considered the most critical defects as they greatly compromise structural integrity.
6. **Overlap**
   Overlap happens when weld metal flows over the edge of the joint without fusing with the base metal. This is usually caused by poor welding technique or low welding current. Even though the weld appears to cover the surface, it does not form a strong bond with the base metal.

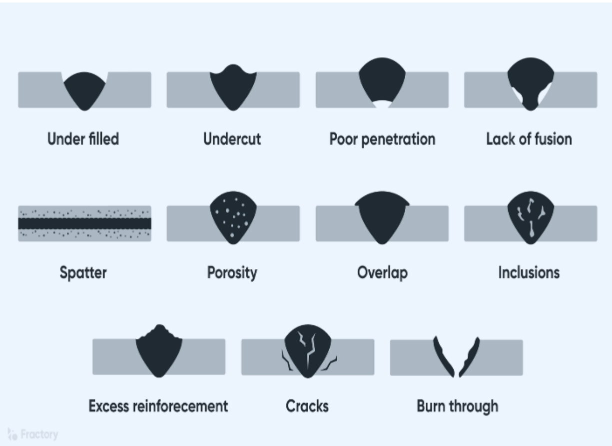

Figure 1. Another Types of Weld Defects

In manual welding practice, these types of defects commonly occur, especially when welding parameters are not well controlled or when the operator lacks sufficient skill. Therefore, understanding each type of defect is essential in order to take the correct preventive or corrective actions. In addition, the use of non-destructive testing (NDT) methods such as visual testing (VT), penetrant testing (PT), or radiographic testing (RT) is very helpful in detecting defects before the product is functionally used [4].

2.4 Factors Causing Weld Defects

Weld defects are one of the main problems in welding processes that can affect the quality, strength, and service life of the joint. The appearance of defects in welds does not occur randomly but is influenced by various technical and non-technical factors. Understanding the main causes of weld defects is essential for preventing structural failure and maintaining consistent production quality [5].

In general, the causes of weld defects can be classified as follows:

Table 1. Factors Causing Weld Defects

No.	Factor Category	Example or Explanation
1.	Welding Process Parameters	Current too high or too low, unstable electrode travel speed, incorrect electrode angle
2.	Material Condition	Base metal surface is rusty, oily, dirty, or damp
3.	Electrode Quality	Damp electrodes, improper storage, electrode type not suitable for the material
4.	Operator Technique and Skill	Inconsistent hand movement, poor control of arc length and electrode angle
5.	Working Environment	Strong wind, damp welding area, or extreme ambient temperature
6.	Preparation and Cleaning Procedures	Slag not cleaned between passes, insufficient inspection before the next weld layer

Understanding the above factors is crucial for controlling weld quality. By identifying the root causes of each type of defect, operators and process planners can take preventive measures such as optimizing welding parameters, conducting operator training, and enhancing quality control both before and after welding. In this study, the analysis of these factors forms the basis for developing technical solutions to improve the quality of carbon steel manual weld joints.

3.0 RESEARCH METHODOLOGY

3.1 Type and Research Approach

This study falls under the category of experimental–descriptive research a method that combines hands-on, experiment-based investigation with descriptive analysis of the resulting data. This approach was chosen because it aligns with the study's main objectives: directly observing the manual welding process on carbon steel, identifying the types of weld defects that occur, and analyzing how those defects relate to the welding parameters applied. Moreover, it allows the researcher to present a clear, measurable picture of real field conditions while offering technical recommendations that can be practically implemented.

As an experimental study, the work involves systematically adjusting several key welding parameters such as current, electrode type, travel speed, and welding position and then examining their effects on weld quality. The test material consists of carbon-steel plates of specific thickness, which are joined using the Shielded Metal Arc Welding (SMAW) process, the most common manual welding technique in light- to medium-scale industries. After welding, each joint is inspected to determine how these parameters influence the nature and number of weld defects observed [6].

In the descriptive component, the experimental results are presented both qualitatively and quantitatively, focusing on defect identification, frequency of occurrence, and likely causes. Data are gathered through direct visual inspection (Visual Testing, VT) and, when necessary, additional non-destructive tests such as Dye Penetrant Testing (PT) to reveal surface defects invisible to the naked eye. The collected data are then classified and analyzed to uncover patterns or trends that form the basis for improvement strategies.

This combined approach is appropriate because it not only tests welding variables in a practical setting but also thoroughly explains cause-and-effect relationships observed in the field. Consequently, the findings should be not only informative but also solution-oriented, serving as a technical reference for enhancing the quality of manual carbon-steel welding across various work sectors. By bridging practical field needs with academic inquiry, this research supports skill development for welders, the refinement of work standards, and the overall improvement of production quality in applications where weld joints are critical to construction or product integrity.

3.2 Research Procedure

The research procedure is arranged systematically to ensure that the data collection process is carried out in a controlled manner and can be scientifically accounted for. This study was conducted through several interrelated stages, starting from material preparation, welding execution, observation of results, up to data analysis.

1. **Material and Equipment Preparation**
   The initial stage begins with preparing the test material in the form of carbon steel plates with a certain thickness (for example, 6 mm or according to the standard used), along with E6013 electrodes commonly used in manual welding. In addition, SMAW (Shielded Metal Arc Welding) equipment is prepared, along with supporting tools such as wire brushes, welding hammers, clamps, and personal protective equipment (PPE). For defect inspection, visual testing tools (flashlight, magnifier, welding gauge) and non-destructive testing equipment such as penetrant testing liquid are also prepared if needed.
2. **Manual Welding Execution**
   Once preparation is complete, the welding process is carried out using the SMAW method with variations in parameters that have been designed beforehand, such as:
   - Welding current (90 A, 100 A, and 110 A)
   - Electrode travel speed
   - Electrode angle
   - Welding position (flat, vertical, or others)

Each weld is performed on a separate carbon steel plate for each parameter variation, so that the results can be objectively compared. The welding operator must maintain consistent technique throughout the process so that the obtained results truly represent the effect of the tested variables.

3. **Weld Inspection**
   After the welding process is completed, the weld joint is allowed to cool naturally before initial observation is carried out. Weld defect inspection is performed using two methods:
   - **Visual Test (VT):** to detect surface defects such as undercut, overlap, slag inclusion, and porosity.
   - **Dye Penetrant Test (PT):** if needed, is used to detect micro-defects or surface cracks that are not visible to the naked eye.
4. **Recording and Documentation**
   Each weld joint is given a code or test number to facilitate identification. Defects found are recorded and documented through photographs, sketches, or observation tables. The data on the number, type, and location of defects become the main reference in the analysis stage.
5. **Data Analysis and Interpretation**
   The data collected from each weld specimen is then analyzed to understand the relationship between welding process parameters and the types of defects that appear. The results of this analysis become the basis for drawing conclusions and formulating technical solutions that are appropriate to minimize or prevent similar welding defects in future manual welding of carbon steel.

By following this systematic procedure, the research is expected to provide an accurate and valid picture of the influence of various factors on weld defects, and serve as a useful reference for welding practice in the field.

3.3 Data Analysis Technique

The data analysis technique in this study was carried out using a descriptive-quantitative approach, aiming to identify the types of welding defects that appeared, analyze their frequency of occurrence, and correlate them with variations in the manual welding process parameters used. This approach was chosen because it aligns with the nature of the data produced from experimental activities conducted directly and practically in the field. The data analyzed originated from observations of carbon steel plates welded using the Shielded Metal Arc Welding (SMAW) method, with various parameter variations such as welding current, type of electrode, electrode travel speed, and welding position.

The initial stage of analysis began with the collection of welding defect observation data through two main methods, namely Visual Testing (VT) and Dye Penetrant Testing (PT). Visual testing was conducted to detect defects that were directly visible on the weld surface such as undercut, overlap, slag inclusion, porosity, or other form-related imperfections. Meanwhile, dye penetrant testing was used to identify micro surface defects not visible to the naked eye, such as fine cracks or small pores hidden on the weld metal surface. The results from these tests were documented systematically, in the form of observation notes, photographic documentation, and defect classification tables.

Each tested weld joint was assigned an identification code to distinguish the parameter variations used. Next, the types of defects found were classified and the frequency of their occurrence recorded for each specimen. This data was then processed into a frequency distribution table to determine the most dominant defect type. Additionally, the data was presented in the form of occurrence percentages, allowing for a quantitative analysis of the extent to which each parameter affected the appearance of specific defects. For instance, the relationship between excessive welding current and the increased frequency of undercut defects or uncontrolled metal spatter could be analyzed [7].

Once the data was processed, a comparative analysis was carried out across parameter variations to determine which settings produced the most defects and which yielded the best weld quality. This process also considered potential cause-effect

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relationships between process settings and defect types, such as the link between overly slow electrode movement and the formation of slag inclusion or overlap. Moreover, external factors such as base metal cleanliness and environmental conditions during welding were also taken into account.

All analysis results were used as the basis for formulating technical solutions to reduce or prevent welding defects. The proposed solutions were tailored to real field conditions, to ensure ease of implementation by welders or workshop technicians. Therefore, the data analysis technique used in this study was not only evaluative in assessing weld quality but also solution-oriented and applicable in the context of improving the quality of manual carbon steel welding processes.

3.4 Evaluation and Validation

The evaluation and validation processes in this study were conducted to assess the accuracy and consistency between experimental results and numerical simulation outcomes related to the galvanic corrosion phenomenon. The evaluation began with a comparison of empirical data such as electrochemical potentials, galvanic currents, and corrosion rates obtained from laboratory measurements with the simulation outputs generated using numerical modeling software. The degree of agreement between the experimental trends and simulation predictions served as a key indicator of the simulation model’s success in representing real-world systems. If the galvanic current values or corrosion distribution patterns for certain metal pairs showed significant discrepancies between the simulation and experimental results, further analysis was carried out to identify potential sources of deviation. These discrepancies could stem from assumptions within the model, such as irregular metal surfaces, local temperature variations, or imperfect solution mixing.

The validation process not only focused on numerical comparisons, but also on the alignment of observed physical phenomena, such as the shape and distribution of corrosion on metal surfaces documented through microscopy. If the simulation model was able to predict the spatial location or intensity of corrosion that corresponded with microscopic observations, the model’s validity was considered high. Furthermore, sensitivity analyses were conducted on key simulation parameters such as pH, temperature, or electrolyte conductivity to determine how changes in conditions affected model outcomes. This approach helped test the robustness of the model under varying scenarios.

Overall, the purpose of the evaluation and validation process was to ensure that the research findings were not only numerically accurate but also reliable in representing the physical behavior of galvanic corrosion. A well-validated model allows simulation results to be used as predictive tools in designing more corrosion-resistant material systems, thereby enhancing the practical value of this research.

4.0 RESULTS AND DISCUSSION

4.1 Identification of Welding Defects

Observations of manually welded carbon steel specimens revealed several recurring and dominant types of welding defects. The identification process was carried out using two primary methods: Visual Testing (VT) and Dye Penetrant Testing (PT). Visual testing was used to detect surface-visible defects on the weld, while penetrant testing was applied to identify cracks or small pores that were not visible to the naked eye. Through these two approaches, sufficiently representative data were obtained to comprehensively evaluate the quality of the welding results.

The most frequently observed defects in this study were porosity, undercut, slag inclusion, and incomplete fusion. Porosity appeared as small holes on the weld surface, caused by gas trapped in the molten metal during solidification. This defect typically occurred due to poor cleaning of the plate surface before welding, or the use of damp electrodes that generated vapor when heated.

Undercut defects appeared along the edges of the weld joint as thin grooves resulting from the base metal melting but not being refilled by the weld metal. These defects were commonly found in welding processes using excessively high current or with uncontrolled travel speed, causing the plate edge to melt too quickly without forming a proper bond. Meanwhile, slag inclusion occurred when slag from a previous weld pass was not thoroughly cleaned and became trapped in the subsequent weld layer. This often resulted from inadequate cleaning after the initial pass or from improper electrode angle during welding.

Incomplete fusion occurred when the weld metal failed to fuse completely with the base metal or between weld layers. This defect was generally found in specimens welded with insufficient current or poor welding technique, such as suboptimal electrode angle and an arc length that was too long. Overall, these four types of defects demonstrated that the quality of welds is strongly influenced by a combination of technical parameters and the welder's skill. Therefore, early identification of the types of defects is a crucial foundation for further analysis regarding their causes and the corrective actions that can be taken to improve the quality of manual carbon steel welds [8].

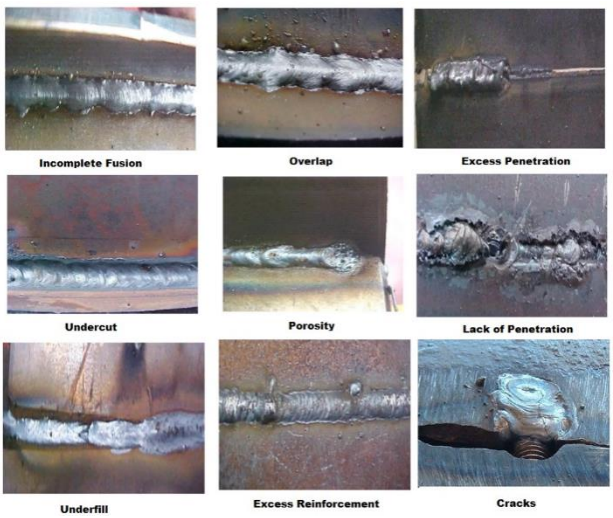

Figure 2. Identification of Welding Defects

4.2 The Effect of Welding Current on Defect Formation

The variation in welding current has a significant effect on the types and number of defects that appear in carbon steel weld joints. At 90 amperes, incomplete fusion defects were frequently

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observed due to insufficient heat generation, which failed to fully melt the base metal. This resulted in weak and shallow bonding between the weld metal and the base metal. Conversely, at 100 amperes, the results were the most optimal. Penetration was adequate, the weld bead was uniform, and the number of defects was minimal. This current level is considered ideal for the material thickness and electrode type used in this study.

At 110 amperes, defects such as undercut and spatter began to appear more frequently. The excessive heat caused the molten metal to become difficult to control, leading to erosion along the edge of the joint and the formation of metal droplets outside the weld path. Among these three current variations, it is evident that selecting the appropriate current level is crucial in manual welding. Both insufficient and excessive current pose risks of defects, thus requiring careful adjustment according to the material conditions and welding technique being applied [9].

4.3 The Influence of Operator Technique and Electrode Travel Speed

The quality of welding results is not only influenced by machine parameters but also heavily depends on the operator's skill, particularly in maintaining the electrode angle, arc length, and travel speed during the welding process. Based on observations, unstable welding techniques often lead to defects such as slag inclusion, overlap, and irregular weld bead shapes. Operators who move the electrode too quickly tend to produce narrow, shallow welds that are prone to incomplete fusion. Conversely, a travel speed that is too slow can result in slag buildup or even overwelding, causing the weld bead to appear bulging and uneven. An electrode angle that is too upright or too tilted can also prevent the molten metal from flowing properly into the joint, leading to defects such as undercut or cold lap.

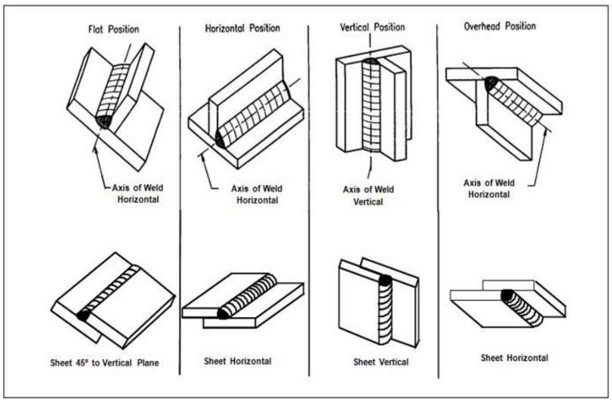

Figure 3. Technique and Electrode Travel Speed

These findings indicate that consistently mastering basic welding techniques including travel speed and hand control is a key factor in producing high-quality, defect-free welds. Practical training and field experience are essential so that operators can accurately adjust their movement and electrode positioning according to real-world working conditions [10].

4.4 Technical Solutions to Reduce Weld Defects

Based on the identification and analysis of the weld defects encountered during manual welding of carbon steel, several relevant technical solutions can be formulated to reduce or even prevent similar defects:

Table1. Technical Solutions to Reduce Weld Defects

No.	Type of Welding Defect	Main Cause	Recommended Technical Solution
1.	Porosity	Dirty metal surface or damp electrode	Clean the metal surface and dry the electrode before use
2.	Undercut	Excessive current, electrode movement too fast	Adjust welding current and stabilize electrode travel speed
3.	Slag Inclusion	Slag not cleaned between welding passes	Thoroughly clean slag before the next welding layer
4.	Incomplete Fusion	Current too low, inconsistent welding technique	Use sufficient current and improve electrode angle and arc length
5.	Overlap	Travel speed too slow or improper movement technique	Maintain appropriate electrode speed and control electrode angle
6.	Crack	Rapid cooling, excessive thermal stress, hard base metal	Preheat if necessary, allow gradual cooling, and apply proper multi-pass welding techniques

By implementing this combination of technical measures, weld quality can be significantly improved—reducing defect rates and extending the service life and reliability of welded structures.

5.0 CONCLUSION AND SUGGESTIONS

5.1 Conclusion

Based on the results of the research conducted, it can be concluded that the manual welding process on carbon steel is strongly influenced by a combination of technical parameters and operator skill. Observations of welded specimens revealed four dominant types of welding defects: porosity, undercut, slag inclusion, and incomplete fusion. These defects are generally associated with improper welding current selection, electrode condition, electrode movement technique, and cleanliness of the base metal surface.

Welding current has proven to play a crucial role in determining joint quality. A current that is too low results in incomplete fusion, while a current that is too high can lead to undercut and spatter. The 100-ampere current was found to be the optimal point in this study, producing the most stable and defect-minimized welds. In addition, inconsistent welding techniques such as excessively fast or slow travel speeds and improper electrode angles were also identified as primary causes of welding defects.

To reduce or prevent weld defects, appropriate technical solutions must be applied, including the selection of suitable current, use of dry electrodes, cleaning of the base metal prior to welding, and improving operator skills through regular training. By addressing these factors, the quality of weld joints on carbon steel can be significantly improved. This research is expected to serve as a practical reference for welding industry practitioners and technical education institutions in their efforts to enhance the quality and efficiency of manual welding work.

5.2 Suggestions

Based on the results of the conducted research, several aspects can be considered to improve the quality of manual welding on carbon steel. First, the selection of welding parameters must be carried out carefully, particularly in determining the appropriate current, electrode travel speed, and welding angle. Improper parameters can be the main trigger for defects such as undercut, porosity, and incomplete fusion. Therefore, it is important for the operator to adjust the working parameters according to the material thickness and the type of electrode used.

Second, preparation of the material and electrode prior to welding must be taken seriously. The base metal surface should be cleaned from dirt, rust, and oil, while the electrode must be kept dry to avoid excessive gas generation that causes porosity. Third, the operator's competence is also a key factor that must be continuously improved. Through regular training, operators can better understand proper welding techniques and maintain stability and consistency during the process, thus minimizing the occurrence of defects caused by human error.

In addition, it is recommended that every welding process be accompanied by quality inspection procedures, both visually and using simple non-destructive testing methods (such as dye penetrant) to detect defects as early as possible. Lastly, to support the findings of this study, further research is suggested with a broader variation of parameters, the use of other welding techniques, and the addition of mechanical testing such as tensile and hardness tests to determine the overall strength of the joint. With these steps, it is hoped that the quality of manual welding on carbon steel can continue to be improved sustainably.

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