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Robotic Gmaw Automation For Superior Weld Quality And Reduced Production Costs

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ABSTRACT

Gas metal arc welding (GMAW) is crucial in the industry, and dedicated efforts have been made to ensure stable, automated joining of parts. However, achieving automatic control for quality weld characteristics remains challenging. Despite the use of various laser sensors, real-time detection of geometry characteristics in the weld formation process is still a daunting task. The current study encompasses the challenges and pipe discontinuities of manual GMAW vis-à-vis automated robotic welding. GMAW is pivotal in industrial production, particularly for automated joining in large-scale pipe manufacturing. This study explores robotic GMA welding to replace manual processes for run-in and run-out tabs in submerged-arc-welded pipes, aiming to improve weld quality and reduce production costs. Experimental results reveal significant enhancements in weld accuracy and reduction of common weld defects associated with manual welding. Through novel robotic angle adjustments and a specialized weaving technique, this approach minimizes tab misalignment and fusion defects, streamlining manufacturing.

Keywords – Automated GMAW, Submerged-arc-welded pipes, Robotic welding optimization, Weld quality enhancement

INTRODUCTION

[1] Gas metal arc welding is widely used in industrial production due to its adaptability to automated processes and higher productivity than other welding methods. It has gained traction in the automotive industry, oil and gas sectors, and fabrication and recovery of parts and structures. Selecting the correct input parameters for each product guarantees the bead shape and technical specifications in welding processes. Finding the right parameter combination is crucial to defining highly efficient processes that produce flawless weld beads with the specified shape and minimal input waste. The quality of a weld is directly influenced by its mechanical and metallurgical characteristics, which are, in turn, dictated by the weld geometry. Extensive studies have been undertaken to analyze weld bead geometry in the GMAW process, aiming to meticulously control operational parameters for critical characteristics such as width, height, and penetration. When controlling weld bead geometry, the principal characteristics considered are width, height, and penetration in various welding processes. Researchers suggest statistical or artificial intelligence models to control these geometric parameters. Additionally, other independent parameters of the power source, like welding speed and shielding gas variations, may also likely be considered.
In filler metal processes like GMAW, disturbances in the weld pool change the shape of the surface and the direction of the reflected rays. These systems are limited to GTAW or GMAW-P processes and should favor small fluctuations in the weld pool. [1][2] GMAW is highly efficient as its electrode/wire is consistently

supplied and thoroughly melted by the electric arc. This has led to increased automation compared to other welding practices. Its rapid deposition rate makes GMAW well-suited for producing complex, large-scale metal parts. When an electric current passes through the main wire to the base metal, it creates a powerful electric arc between the consumable wire and the welded material. This arc generates a significant amount of heat, which is essential for welding. However, it also transfers heat to the base metal, potentially causing excessive heat buildup during welding. Various technological advancements have been developed to control or reduce the temperature of the base metal while preventing the wire from melting. Recommended methods include automatic GMAW, controlled short-circuiting, and ice welding. [2]

[3] Advancements in welding aim to reduce welder exposure to welding fumes by using automated welding stations. This allows welders to take on additional tasks and oversee other machinery, ultimately reducing production time. [3][4]The welding process can be broken down into three main phases. In the setup phase, parameters are adjusted, and the system is prepared, including planning the torch's path, determining the distance between the contact tip and the workpiece, adjusting the gas composition and flow rate, selecting the wire size and type, and more. The execution phase is when the actual welding takes place, involving factors such as the current flowing through the arc, arc voltage, torch movement speed, torch angle, workpiece cooling rate, and heat and mass transfer. The final phase, known as the output phase, is when the weld is formed, and its characteristics, such as shape, depth, microstructure, strength, defects, and other physical attributes, are observed. The initial input factors in welding are factored by the method devised, while the execution factors depend on the physical process and resulting disruptions. This leads to welds showing output traits influenced by these factors. The demands and obstacles faced by a measurement system of various sensor technologies are considerable, as these sensors need to be coordinated to collect data on specific variables across all steps due to the complexity of the procedure. Different sensor technologies offer unique benefits and challenges for use before or after welding. For example, radiography and ultrasonic sensing provide insights into the weld's interior, while laser profiling and high-resolution cameras focus on surface quality. However, these technologies also face challenges such as speed, evaluation time, cost, durability, and accessibility, which can limit their effectiveness for real-time quality checks. Through-arc sensing is an adaptable and user-friendly online solution for welding, as it monitors arc voltage and current to identify patterns and detect malfunctions. Additional real-time monitoring can track temperature and sound profiles. However, it doesn't directly indicate weld quality, so a mapping technique is needed for assessment. [4]

Traditional manual welding methods often fail to deliver uniform quality at the pipe ends, leading to rework and increased costs. This research addresses the lack of consistent automated solutions for improving weld end quality in submerged-arc-welded pipes. Through robotic modifications, this study aims to provide insights into enhancing end-of-pipe weld accuracy and stability.

AUTOMATIC (ROBOTIC) PROCESS FOR WELDING WELD TABS

The process of welding tabs on an API-grade pipe involves setting the SAW welding settings on both the pipe's front and back. Correctly welded tabs improve the accuracy of laser tracking during SAW welding and ensure smoother welding starts, leading to more precise control over the pipe's end cut-off during Non-Destructive Testing (NDT) processes, which include X-Ray and Radiography. The tabs are cut from the pipe's schedule and then fixed to the pipe's front and back for the SAW welding's initial and final stages. The dimension of the Run-In and Run-Out tabs for ID/OD welding will be: 300 ± 20 mm x 200 ± 20 mm.

Fig (1) – Typical setup for Automatic (Robotic) Process for Welding Weld Tabs

Fig (1) Collect and stack tabs in tab cassettes and place inside pick and place robot.

Weld tabs can be either on the inside only, or on both the inside and outside, with a weld length close to 6 inches. The position of the tab should be about 2 to 3/8 inches away from the weld seam, on one side of the tab's edge. Make sure the robot is in its home position, and then activate the auto start feature by pressing the start button. Weld tabs should be placed on both the inside and outside of the pipe, with a weld length of about 6 inches on each side of the groove, and an additional 3 inches on each side of the groove. Below are images and detailed explanations for each step of the process. For the Weld tab joining process, required specific dimension of the Run-In and Run-Out tabs for ID/OD welding will be: 350 ± 15 mm x 200 ± 10 mm (14 ± 0.5 inches x 8 ± 0.5 inches).[5]

MATERIAL AND METHODS –

Robotic TAB welding problems with contribution in Daily Rework with NDT defects analysis.

Welding process defects associated with robotic Tab welding with both pipe ends are listed below and these defects.

Fig (2) - Robotic welding technique string gives more weld bead height.

Fig (2) Above explain the discontinuities type as excessive weld bead height can cause lack of penetration (LOP) defect in welding, leading to cutting off the pipe end during NDT as a defect.

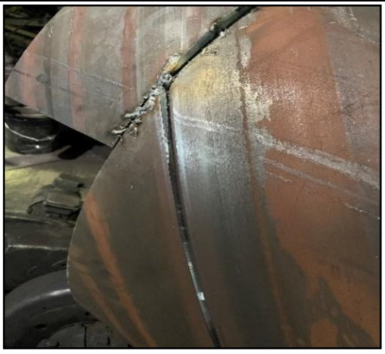


Fig (3) - Robotic welding appears uneven with welding parameters fluctuation.

Fig (3) - Explain the defect type as uneven weld bead height makes it look like burn-through (BT) during welding, leading to pipe end cutoff from NDT as a defect.

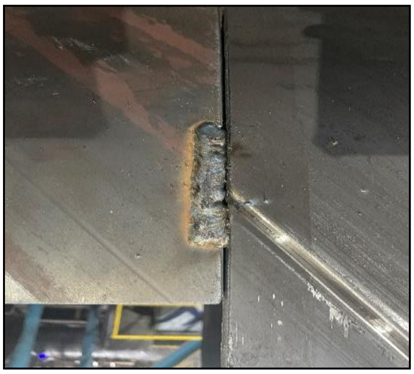


Fig (4) - Robotic welding shifted towards run in tab.

Fig (4) Explain the defect type as Due to a shifted weld bead on the run-in tab and a lack of proper joint with the pipe edge, it appears as burn-through (BT) during welding, so the pipe end was cut off as a defect during NDT.

Fig (5) - Robotic welding shifted offset with one side of pipe edge.

Fig (5) Explain the defect as offset shifting of the weld bead on the run-in tab with the pipe edge has led to under fill during welding, resulting in the need to cut off the pipe end as a defect as per NDT standards.

Fig (6) - Robotic welding done offset with pipe edge.

Fig (6) Explain the defect as offset welding on the run-in tab with the pipe edge has caused a lack of side wall fusion (LOF) due to poor laser tracking during welding. As a result, the pipe end cutoff is considered a defect in non-destructive testing (NDT).

Fig (7) - Gap observed during robotic welding on the pipe edge.

Fig (7) Describe the issue as the incorrect placement of the tab on the table while welding led to burn through (BT) and insufficient fusion of the side wall (LOF) because of inadequate laser tracking, which caused a separation. As a result, the pipe end was removed during the non-destructive testing (NDT) examination because of these flaws.

Fig (8) - Robotic welding shifted towards edge of pipe.

Fig (8) – Explain the defect as the misaligned weld bead at the pipe edge and the lack of a proper connection, it looks like there's a burn-through (BT) and under-filled area during welding, leading to the pipe end being marked as defective due to the NDT inspection.

Fig (9) - Run in / out Tab Robotic welding broken.

Fig (9) Explain the defect as inadequate welding at the pipe edge and the run-in/out tab, the pipe broke before the Submerged Arc Welding (SAW) process began. Consequently, the SAW process commenced on the pipe without the tab. This unwelded section of the pipe was removed due to a lack of penetration (LOP) identified as a defect by Non-Destructive Testing (NDT).[6,7,8,9]

RESULTS AND DISCUSSION –

Contribution of Robotic welding problems in daily rework data by Non Destructive Testing (NDT)

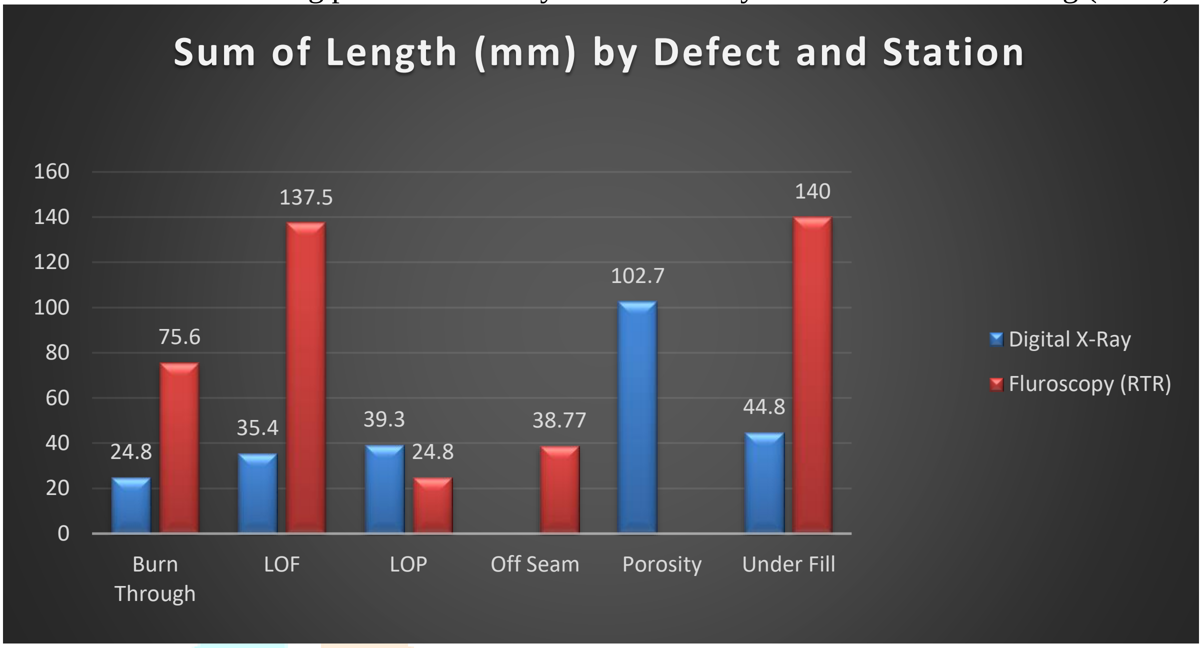


Fig (10) - Data representation for contribution of defects in Daily rework (Before)

Fig (10) Explain the daily rework data generated from NDT department, Digital X-Ray and Fluoroscopy (RTR) for the welding process defects in both ends of pipes.

DEVELOPMENTS FOR ROBOTIC WELDING AND SETUPS FOR MINIMIZING THE PROCESS DEFECTS.

Modification for Tab cassette holder – The tab cassette holder table is crucial for positioning the weld tab accurately with the pipe in the direction of the bevel groove as shown in Fig (11) & Fig (12). Once the weld tab is correctly positioned, the slider forcefully moves the tab near the edge of the pipe, ensuring a strong and defect-free join.

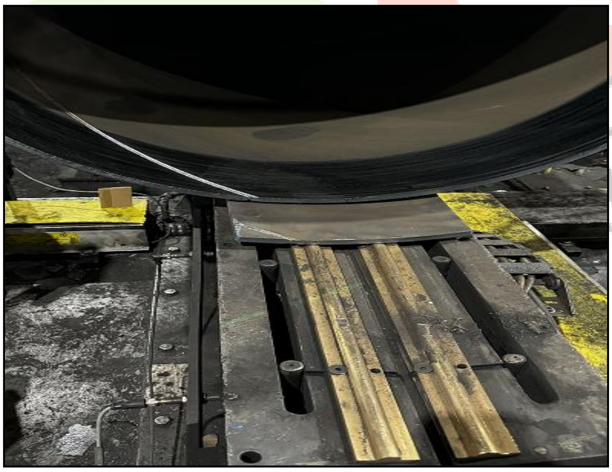


Fig (11) - Modification for Tab cassette holder (Before)

Fig (11) Explaining the condition before modification, the supporting bar design of the tab cassette holder was changed to a triangular shape to securely hold the weld tab with pressure, effectively minimizing gaps and ensuring precise alignment with the pipe.

Fig (12) - Modification for Tab cassette holder (after)

Fig (12) Explaining the condition after modification for the Tab cassette holder. After positioning the weld tab, the slider must be used to move the tab near the edge of the pipe with pressure to ensure a defect-free join. Before and after welding the tabs with the pipe, the alignment of the tab must be checked.

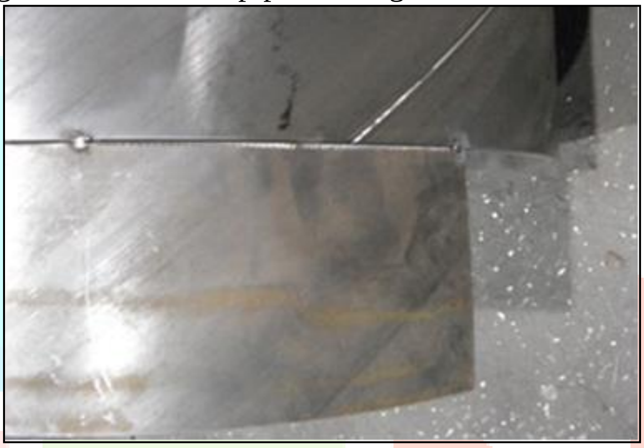


Fig (13) – Proper position of Tab to the pipe.

Fig (13) Explaining the position the tab on the pipe so that its right edge is exactly 4 inches to the right of the OD bevel. Secure the tab with tacks at specified locations and then weld according to the provided measurements. It's crucial to always weld in the flat position, made 12-inch straight edge, ensure the tab is square and aligned with the pipe's outer surface.

ADJUSTMENT OF ANGLE OF ROBOTIC ARM WITH SPECIFIED WELDING POSITION –

In a robotic program, XYZ directions are used for parallel (XYZ) + rotation shifting. The coordinate system—machine, user, absolute, tool, or work coordinates—serves as the reference. You must specify shift amounts by inputting numerical values directly or moving the robot manually and using the movement amounts as the shift amounts.

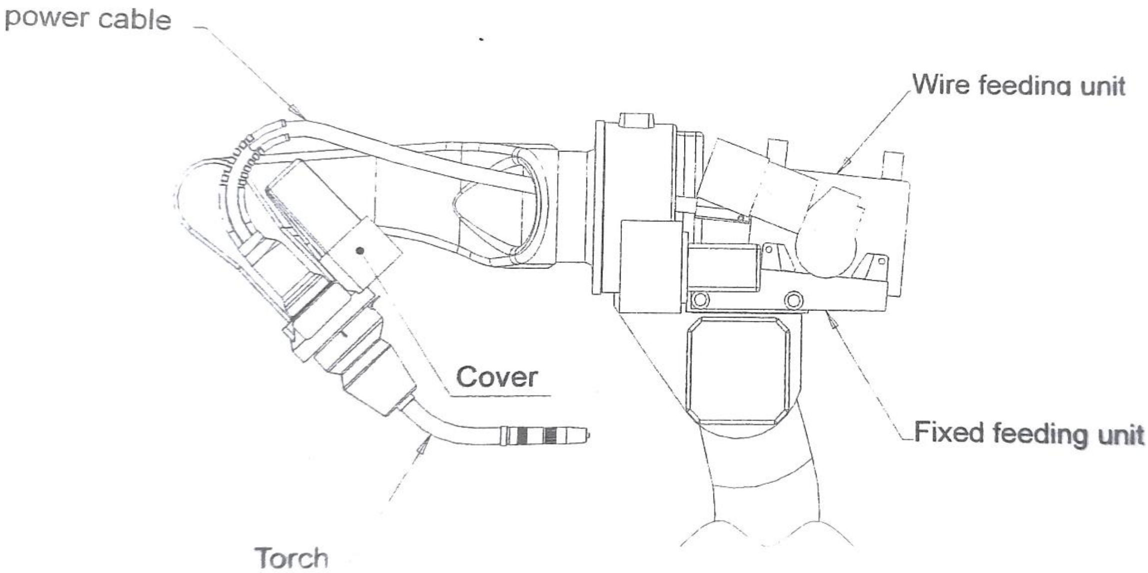
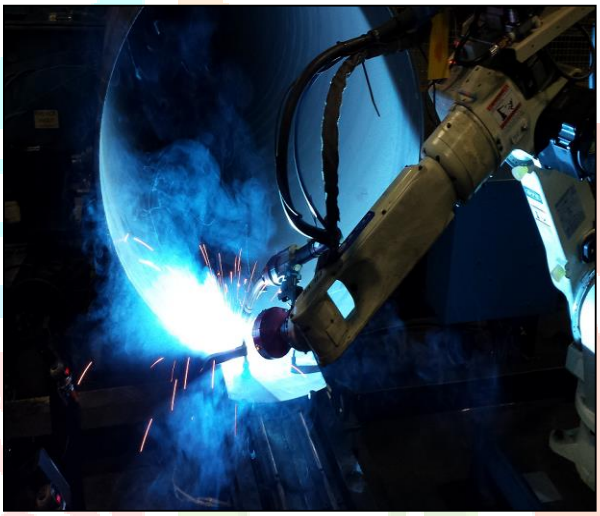


Fig (14) – Adjusting procedure of the torch of robotic arm

Fig (14) – Explaining the robotic arm rotation of the torch centers for the movement directions in the machine coordinate system (for the arc welding application for tab joining).



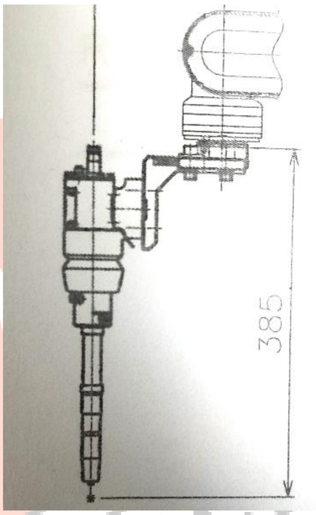


Fig (15) – Welding torch position (Before) Fig (16) – Welding torch position (Before)

Fig (15) and Fig (16) Explaining the condition before Modification.

Robotic arm rotation of the torch centers on the torch line while the torch posture remains fixed and the tool tip is fixed.

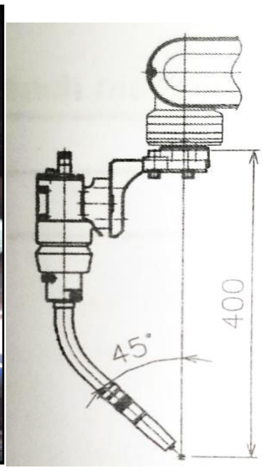


Fig (17) – Welding torch angular position (After) Fig (18) - Welding torch angular position (After)

Fig (17) and Fig (18) – Explaining the welding position after Modification.

The rotation of the sixth axis rotation center line centers on the Z axis while the tool tip is fixed with angular position.

DEVELOPMENT OF WEAVING TECHNIQUE FOR ROBOTIC WELDING –

The wave frequency is a parameter used to adjust the ripple pitch of beads shaped like fish scales in the DC wave pulsed method. The ripple pitch can be fine-tuned as desired by controlling the welding speed and wave frequency.

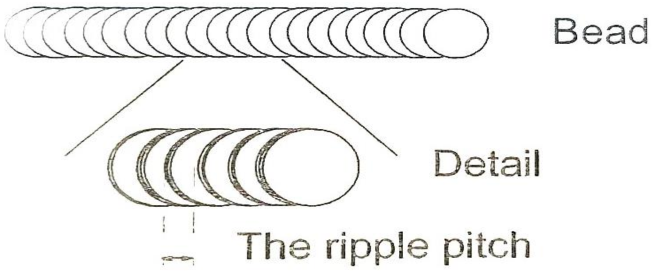


Fig (19) – Robotic welding bead profile for tab welding with pope ends.

Fig (19) – Explaining the welding profile for tab welds with pipe ends. Increasing the wave frequency while the welding speed fixed reduces the pitch width, conversely reducing it increases the pitch width.

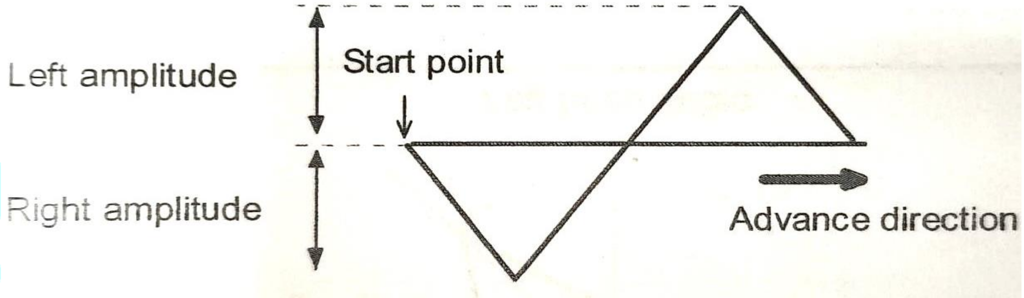


Fig (20) - When oscillation start is on the right side

Fig (20) – Explaining the weaving pattern, when oscillation start is on the right side. This is the weaving frequency (number of waveforms per second). This condition is for setting the weaving amplitude when the linear function or trigonometric function has been set as the operation pattern.

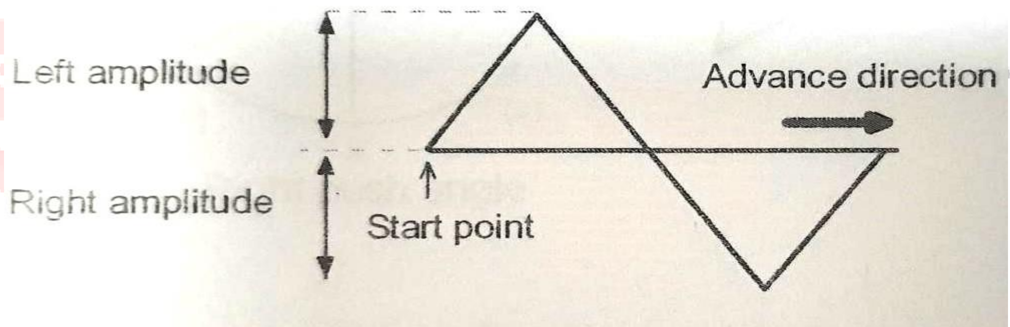


Fig (21) - When oscillation start is on the left side

Fig (21) – When the weaving pattern starts with oscillation on the left, the setting determines whether the weaving begins on the right or left relative to the advance direction. Initially set to the right, the weaving starts from the right side relative to the advance direction. This setting also determines the weaving angle from the main path for both left and right amplitudes.

In the DC wave pulsed method, the wave frequency definitively adjusts the ripple pitch of fish scale-shaped beads. By controlling the welding speed and wave frequency, precise tuning can be achieved to produce the desired result.

CONCLUSIONS –

The robotic welding system's parameters were modified, focusing on the angle of the robotic arc and the development of a weaving pattern to maintain weld stability. These adjustments were crucial in minimizing defects associated with groove placement and alignment at the tab joins.

Developments for Robotic Welding and Setups for minimizing the process defects reflects the quality and productivity in the welding process. These three modifications related to minimize the process defects of GMAW by robotic are effective. [10]

1. Modification for Tab cassette holder.
2. Adjustment of angle of Robotic arm with specified welding position.
3. Development of weaving technique for robotic welding.

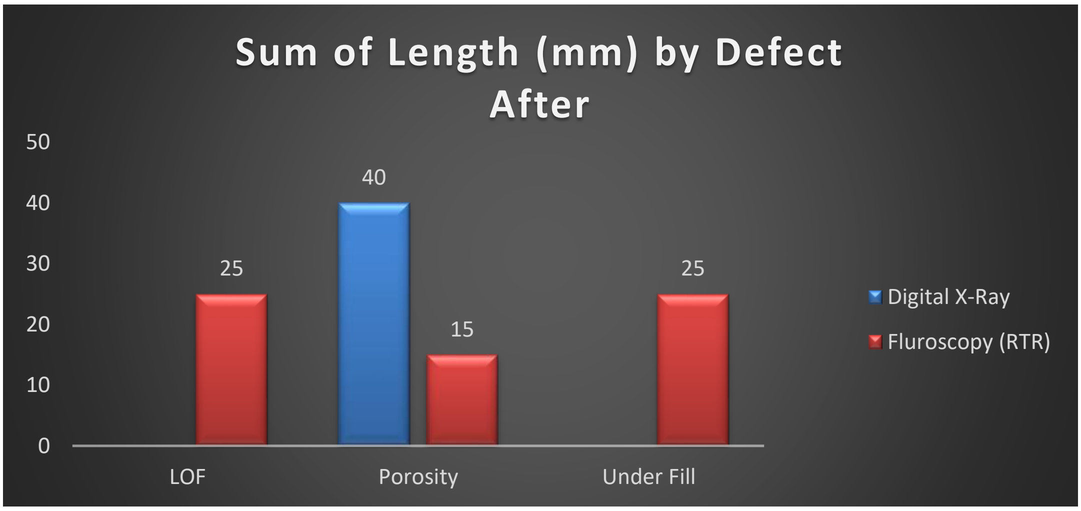


Fig (22) - Contribution of Robotic welding problems (after modification) in daily rework data by Non Destructive Testing (NDT).

Fig (22) Explaining the reducing trend for defects cut off length from Digital X-ray and Fluoroscopy (RTR) stations of NDT. After the modification defects and cut off length from pipe end reduced.
After implementing the robotic adjustments, defect occurrences such as burn-through and lack of penetration were significantly reduced. This indicates that optimized tab placement and robotic arm angle contribute to weld integrity, lowering the probability of rework.

This study presents a novel approach to automated GMAW for submerged-arc-welded pipes, focusing on robotic angle adjustments and optimized tab placement for superior weld quality. Our findings indicate that robotic automation in tab welding reduces production costs by minimizing rework and achieving stable weld quality. Future studies can build upon these innovations to further refine automated welding in the industry.

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