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GTAW Welding Repair Quality Analysis on Sparger Header with Liquid Penetrant and Leak Test

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ABSTRACT

Damage to sparger headers, such as material thinning and leakage, can reduce system reliability and disrupt industrial operations. Repair welding using Gas Tungsten Arc Welding (GTAW) is commonly applied; however, its quality must be verified to ensure safe reuse. This study evaluates the quality of GTAW-based repair welding on a corrosion-damaged sparger header using Non-Destructive Testing (NDT), namely Liquid Penetrant Testing (LPT) for surface defect detection and leak testing for sealing performance under pressurized conditions. Unlike previous studies that focus on newly fabricated welds under laboratory conditions, this study evaluates repair welding performance on an actual industrial component affected by corrosion-induced wall thinning. The combination of surface inspection using LPT and functional validation through leak testing under real operating conditions provides a more comprehensive assessment of repair quality. Results show no surface indications in LPT and no leakage during testing at 1.2 kg/cm² for 37 minutes. These findings indicate that the repaired weld meets acceptance criteria and is suitable for reuse. The results provide a reliable basis for assessing repair welding quality in industrial components.

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INTRODUCTION

In manufacturing and fabrication industries, product quality is a critical factor influencing operational efficiency, system reliability, and workplace safety (Phalane & Gupta, 2023). In addition, high product quality contributes to maintaining industrial competitiveness in global markets (Yudhistira et al., 2025) and reducing costs associated with product failure (Efriandi, 2023). Therefore, ensuring consistent quality in critical manufacturing processes, particularly welding, becomes essential to minimize defects and maintain the performance and reliability of engineering components.

Component performance is determined not only by material properties but also by manufacturing processes, particularly welding, which is widely applied as a permanent metal joining technique (Sudrajat & Akbar, 2023). When properly controlled, welding processes can produce joints with high structural performance and durability (Jati et al., 2024). However, in practical applications, variations in welding parameters and environmental conditions may lead to inconsistencies in weld quality, thereby increasing the potential for defect formation and performance degradation.

However, welding processes are inherently prone to defects such as cracks, porosity, and lack of fusion, which may degrade mechanical properties and increase the risk of structural failure (Ardian et al., 2023). These defects are particularly critical for components operating under pressure and fluid transport conditions (He et al., 2022), as they directly affect system reliability and operational safety. Therefore, effective quality control is required to ensure compliance with engineering standards (Zelinko et al., 2021).

Non-Destructive Testing (NDT) is widely applied in industrial inspection to evaluate weld quality without damaging the component. Liquid Penetrant Testing (LPT) is commonly used for detecting surface-breaking defects such as cracks and porosity based on capillary action. However, LPT is limited to surface inspection and does not provide information related to sealing performance or operational leak-tightness.

For pressurized components, leak testing is required to evaluate sealing performance under operational conditions. This method assesses the ability of a component to prevent fluid leakage under applied pressure (Fajrin et al., 2024). Leak testing is essential in ensuring operational safety and preventing failures that may arise from undetected leakage (Mubarok & Machfuroh, 2024). However, leak testing alone does not provide information regarding surface integrity or the presence of micro-scale welding defects, thus highlighting the need for complementary inspection methods to achieve a more comprehensive evaluation of repair welding quality.

In industrial maintenance practice, repair welding is widely applied to restore degraded components without full replacement (Monalita et al., 2022). One common degradation mechanism is corrosion-induced wall thinning, which reduces structural thickness and increases susceptibility to leakage (Song et al., 2023). Although repair welding provides a practical solution, improper execution may introduce additional defects; therefore, post-repair inspection is required to ensure structural performance.

Previous studies have mainly focused on weld quality in newly fabricated components under controlled laboratory conditions (Rauf Al Faiq et al., 2025). However, limited research has addressed repair welding under actual industrial corrosion conditions. In addition, many studies rely on a single inspection method, which may not be sufficient to evaluate both surface condition and functional performance.

Therefore, this study investigates GTAW-based repair welding of a sparger header component affected by corrosion-induced wall thinning and leakage under actual industrial conditions. The repair quality is evaluated through surface condition and leak-tightness assessments using Liquid Penetrant Testing (LPT) for surface defect detection and leak testing for sealing performance under pressurized conditions.

METHOD

The material investigated in this study was a sparger header component coded RE-C215, which had experienced localized wall thinning due to corrosion degradation during in-service operation. The degradation resulted in a reduction of wall thickness in the affected region, thereby compromising the structural integrity and leak-tightness of the component. The base material of the sparger header use the ASME standard was SB-575 UNS N10276.

To restore structural integrity, a repair welding procedure was applied using a patch plate technique. The repair material selected was SB-575 UNS N10276, a nickel-based alloy known for its superior resistance to corrosion and aggressive chemical environments. The patch plate was designed with a thickness of 4 mm to meet or exceed the original wall thickness and ensure adequate mechanical strength after repair. he material used in this study was a sparger header component RE-C215 that had experienced localized wall thinning due to corrosion degradation. The repair was conducted using a patch plate welding method with SB-575 UNS N10276 as the repair material. The overall repair process of the sparger header is illustrated in Figure 1.

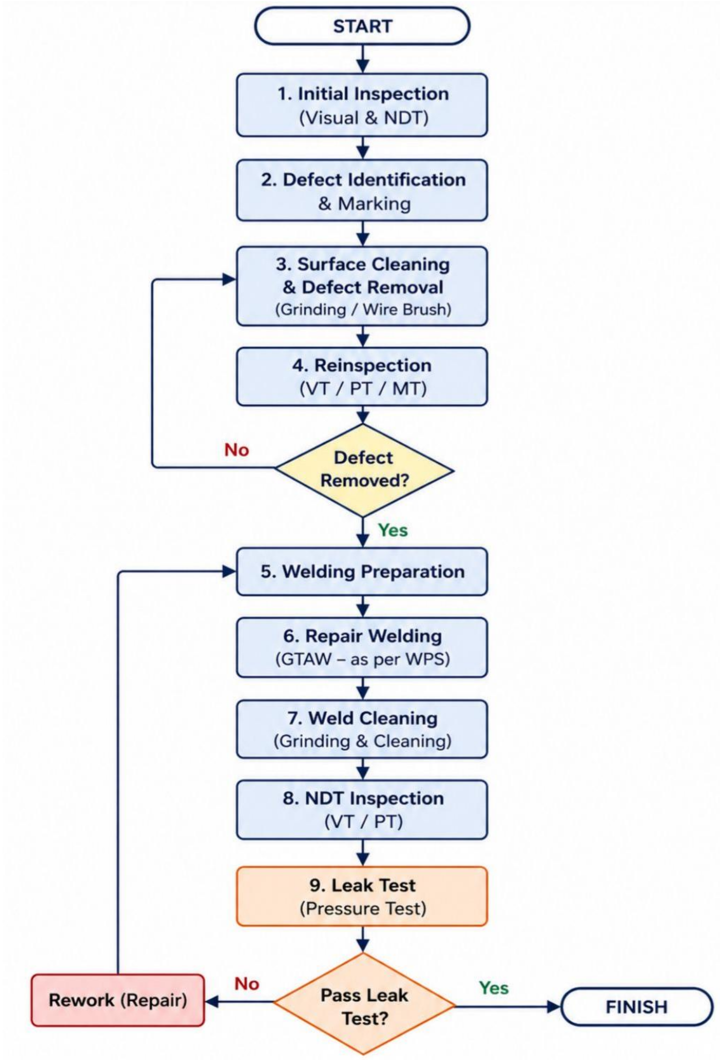

Figure 1. Repair process flow diagram of sparger header

RESULTS AND DISCUSSION

The LPT examination identified surface-breaking indications in the weld area of the sparger header RE-C215, confirming the presence of localized surface discontinuities. These indications correlate with leakage observed during field inspection, indicating compromised surface condition as shown in Figure 2.

Figure 2. LPT results showing surface indications on the weld area

The detected damage is characterized by localized wall thinning, which is typically associated with corrosion and/or erosion mechanisms under continuous exposure to process fluids. Such degradation leads to a progressive reduction in effective wall thickness, resulting in increased stress concentration and a significant decline in the pressure containment capability of the component. As the wall thickness decreases below the design allowance, the component becomes more susceptible to leakage and potential failure under operating pressure. This degradation mechanism has been widely recognized as a critical failure mode in pressure-retaining equipment operating in corrosive environments (Song et al., 2023), particularly in systems subjected to long-term chemical exposure and elevated temperatures.

The degraded region was restored using a patch plate repair technique to re-establish structural continuity and thickness, as shown in Figure 3. This method is suitable for components with significant localized material loss where reinforcement is required rather than surface-level repair (Monalita et al., 2022).

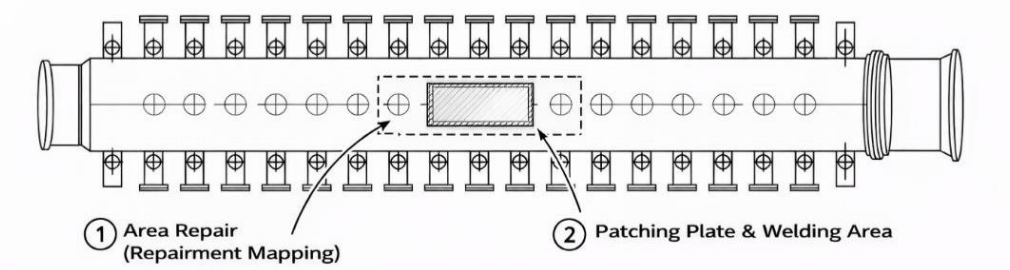

Figure 3. Repair mapping of patch plate installation on the sparger header

GTAW was applied along the patch boundary to ensure metallurgical bonding between base metal and patch material. Controlled heat input is critical to minimize weld discontinuities such as porosity and lack of fusion that may compromise structural performance. Post-repair evaluation confirmed continuous weld formation and absence of visible surface discontinuities.

Liquid Penetrant Testing Results

The Liquid Penetrant Testing (LPT) results identified no surface-breaking indications in the repaired weld area of the sparger header RE-C215, demonstrating that the weld surface satisfies the specified acceptance criteria, as shown in Figure 4. This result indicates that the repair welding process successfully restored the surface integrity of the component. The absence of detectable indications suggests that critical surface defects such as cracks, porosity, and lack of fusion were effectively minimized during welding.

Figure 4. Liquid penetrating testing results of the repaired sparger header

Welding defects are generally associated with improper parameter selection, inadequate shielding, and contamination during the welding process (Rizvi & Alib, 2019). In this study, the controlled application of GTAW parameters, combined with proper surface preparation and interpass cleaning, contributed to stable arc conditions and reduced the likelihood of defect formation. This finding is consistent with previous studies (Xie et al., 2022), which reported that appropriate control of welding variables significantly improves weld surface quality and reduces defect occurrence.

Leak Testing Results

Leak testing was conducted to evaluate the sealing performance of the repaired welded joint under pressurized conditions, as shown in Figure 5. (Zygmuntowicz et al., 2021). The test results demonstrated stable pressure conditions with no evidence of bubble formation or fluid seepage throughout the holding period, indicating that the repaired weld achieved adequate leak-tightness performance. This confirms that the welding process successfully restored the pressure-retaining function of the component.

Unlike surface inspection methods, leak testing provides direct validation of functional integrity by assessing the ability of the weld joint to withstand internal pressure without leakage. Non-destructive testing (NDT) methods are widely applied to evaluate weld quality and detect both surface and subsurface defects in engineering components (Rogalewicz et al., 2023).

Figure 5. Leak testing setup/result of sparger header RE-C215

However, the effectiveness of leak testing in this study highlights its critical role in complementing conventional NDT techniques, particularly in confirming the operational performance of repaired components. This is consistent with recent studies emphasizing the importance of combining multiple NDT approaches to improve the reliability of weld quality assessment in industrial applications (Shaloo et al., 2022).

Table 1. Leak testing results of repaired sparger header

Testing Parameters	Average value	Standard	Results
Leak Testing Pressure	1.2 kg/cm²	≥ 1 kg/cm²	Pressure achieved and stable
Holding Time	37 minutes	≥ 30 minutes	Test time met standards
LPT Results	-	No Indication	No surface defects found
Leak Testing Results	-	No Indication	No bubbles, no seepage

Integrated Analysis of Liquid Penetrant Test Result and Leak Testing Results

The evaluation of repair welding quality was conducted through an integrated approach combining Liquid Penetrant Testing (LPT) and leak testing to assess both surface integrity and functional performance of the repaired sparger header. The LPT results showed no surface-breaking indications in the weld area, confirming that the repaired joint satisfies the specified acceptance criteria and indicating the absence of critical surface defects such as cracks, porosity, and lack of fusion. This suggests that the applied GTAW parameters, along with proper surface preparation and interpass cleaning, were effective in minimizing defect formation and ensuring a sound weld surface.

However, surface integrity alone is not sufficient to guarantee the operational reliability of pressure-retaining components. Therefore, leak testing was performed to evaluate the sealing performance of the repaired weld under pressurized conditions. The results demonstrated stable pressure with no observable leakage, bubble formation, or pressure drop during the holding period, confirming that the repaired joint achieved adequate leak-tightness performance. This indicates that the weld not only meets surface quality requirements but also successfully restores the pressure containment function of the component.

The combined results from LPT and leak testing provide a more comprehensive validation of repair quality. While LPT is effective in detecting surface-breaking defects, it does not assess the functional behavior of the weld under operating conditions. Conversely, leak testing directly evaluates the ability of the weld to prevent fluid escape under pressure but does not identify the presence of micro-scale surface discontinuities. The absence of indications in both tests suggests that the repair welding process achieved both structural soundness and functional integrity.

This integrated evaluation approach is particularly important for components operating in corrosive and pressurized environments, where failure may occur not only due to visible defects but also due to inadequate sealing performance. The findings support the concept that combining multiple NDT methods enhances the reliability of weld quality assessment, as also highlighted in previous studies. Therefore, the integration of LPT and leak testing provides a robust and practical framework for validating repair welding performance in industrial applications, especially for in-service degraded components.

Cause - effect analysis and Fishbone Diagram

The fishbone diagram analysis indicates that defects in the sparger header component are influenced by several main factors, including material, method, measurement, and operating conditions (environment). Among these, material-related aspects were identified as the primary contributors, particularly those influenced by operating environmental conditions.

The analysis results show that material degradation in the form of thinning occurs due to prolonged exposure to corrosive process fluids and relatively high operating temperatures. This condition results in progressive material thinning, which increases the likelihood of leakage in the sparger header component.

In line with these findings, environmental factors such as humidity, temperature, and oxygen content in the air significantly influence the corrosion rate of materials, as these conditions accelerate electrochemical reactions on metal surfaces (Lawal et al., 2023). Material degradation is influenced by the interaction between the material and its environment, such as temperature and fluid media, which can lead to a reduction in mechanical properties due to corrosion processes (Sofian et al., 2022). Meanwhile, method and measurement aspects play a supporting role in influencing defect identification and handling processes, as illustrated in Figure 6.

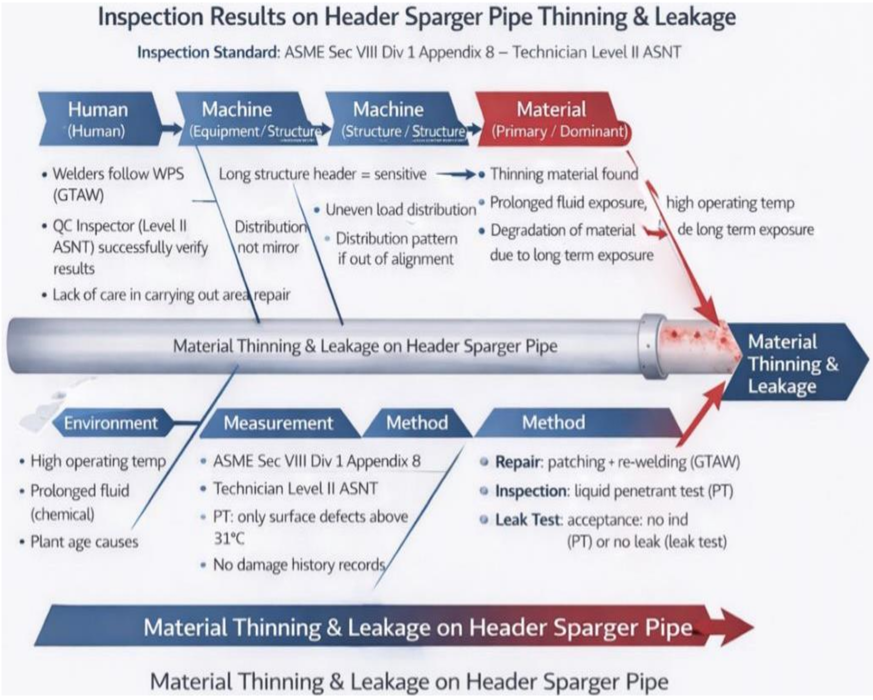

Figure 6. Fishbone diagram of defect causes in sparger header component

The repair strategy applied in this study involved repair welding using a SB-575 UNS N10276 patch plate, which offers superior corrosion resistance compared to the original material, thereby enhancing the durability of the repaired component.

CONCLUSION

The GTAW-based repair welding using SB-575 UNS N10276 was effective in restoring the performance of the sparger header component affected by corrosion-induced wall thinning and leakage. The evaluation results showed no surface defects in Liquid Penetrant Testing (LPT) and no leakage under pressurized conditions, indicating that the repaired component meets the required acceptance criteria and is suitable for operational reuse.

These findings support the research objective of assessing repair welding quality under industrial conditions and provide a practical basis for evaluating similar repair applications. Future work may involve additional testing methods or long term performance evaluation to further improve the reliability of repair assessment.

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