Project Management Institute.
Kingdom of Saudi Arabia

Digital Insights:

Enhancing Weld Integrity in Pipeline Projects: Overcoming NDT Limitations through Procedure Optimization

By: Maytham Sadah & Misfer Zahrani

Project
Management
Institute.
Kingdom of Saudi
Arabia

This paper illustrates a real-world challenge encountered during a high-stakes pipeline construction project, where undetected transverse weld cracks posed a potential threat to both schedule and integrity. Despite deploying a pre-approved Automated Ultrasonic Testing (AUT) procedure aligned with industry norms, these defects remained unnoticed until supplemental Radiographic Testing (RT) was employed. The project team activated a structured quality response, utilizing the root cause analysis process advocated by the Project Management Institute (PMI) to isolate the issue, mitigate immediate risks, and prevent recurrence. The cracks were traced to copper contamination caused by backing shoes, in conjunction with excessive heat input due to low travel speed according to approved Welding Procedure Specification (WPS) deviations. The corrective strategy involved the AUT method with added transverse scanning channels, enforcing WPS compliance by locking travel speeds, expanding inspection protocols with mockups, establishing maintenance for copper shoes, and conducting quality awareness training. These measures ensured continued progress and improved inspection effectiveness for the future.

Project Management Institute. Kingdom of Saudi Arabia

ABSTRACT

During the execution phase of a large-scale mechanized welding program for an onshore pipeline construction project, a significant quality concern emerged when transverse cracks were detected in two weld joints out of a total of 4,225 completed welds. These critical defects were initially undetected by the pre-approved Automated Ultrasonic Testing (AUT) procedure, which was routinely used as the primary non-destructive testing (NDT) method for weld inspection for mechanized welded joints. However, the cracks were eventually identified through supplemental Radiographic Testing (RT), which was implemented as an additional verification step Following RT confirmation and based on the AUT technician's recommendation, concerns were raised about weld quality in specific sections of the pipeline welds.
A thorough metallurgical investigation was conducted to determine the root cause of the defects. The analysis confirmed that the cracking was a result of Copper Contamination Cracking (CCC), a type of weld metal cracking initiated by the presence of copper contaminants. These contaminants were traced back to the use of copper-based backing shoes during the mechanized welding process. The likelihood of cracking was further exacerbated by deviations from the approved Welding Procedure Specification (WPS), particularly related to excessive heat input caused by abnormally low travel speeds during weld passes.

1. INTRODUCTION

Mechanized Gas Metal Arc Welding (GMAW) is widely adopted in pipeline construction due to its efficiency and repeatability. However, it poses unique challenges in defect detection, especially when relying on an NDT method with limitations. In this case, the initially approved AUT technique failed to identify critical weld defects, necessitating a comprehensive root cause analysis and procedural overhaul. The investigation underscores the need for continuous validation of inspection methodologies in high-integrity pipeline projects (ASME B31.8, API 1104).

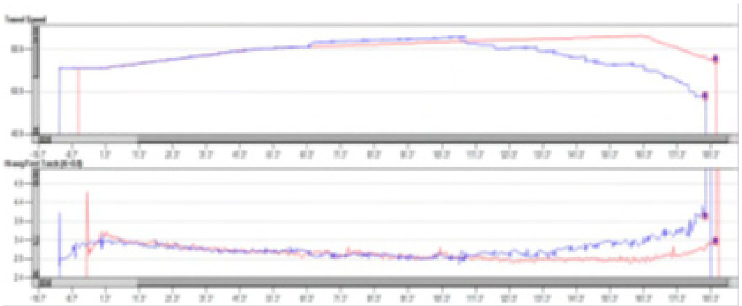
2. PROBLEM STATEMENT AND INITIAL OBSERVATIONS

Following RT scans on selected welds, transverse cracks were discovered in two joints. These defects were not detected by the original AUT procedure, raising concerns about the method's sensitivity. RT film review revealed the presence of a single major crack, while further metallurgical sampling uncovered 18 microcracks in the same region, significantly exceeding initial estimates.

3. ROOT CAUSE ANALYSIS (RCA)

3.1. PRIMARY CAUSE: COPPER CONTAMINATION CRACKING (CCC)

Metallurgical failure analysis confirmed the cracks were caused by copper contamination originating from copper-based backing shoes. Under conditions of excessive heat input and reduced travel speed, molten copper infiltrated the weld pool, causing embrittlement and subsequent cracking (Ref: ASM Handbook Vol. 11, Failure Analysis and Prevention).



From the analysis above (Why-Why analysis)

Project Management Institute. Kingdom of Saudi Arabia

1. Excessive high heat input resulting from low travel speed due to lack of boundaries for the required travel speed for the mechanized welding process within the WPS parameters.
As per pWPS only Oscillation and Travel Speed were allowed to be adjusted by the welder within the WPS range for Travel Speed. However, during the production welds, welders failed to maintain the boundaries for the required travel speed for the mechanized welding process within the WPS parameters. The welding operator unknowingly and unintentionally reduced the travel speed beyond the WPS ranges.

2. Failure to control copper shoe whenever signs of deterioration are detected.

3. Flaw of a quantifiable method of inspection for the Mechanized Welding Process, making emphasis in copper shoe control before and after welding of root and hot-passes.

4. Inadequate welding operator training could be one of the root-causes that welding operators were reducing the TS.

5. One of the causes for the failure to identify the defect right after the welding was that the approved AUT procedure did not consider a transverse channel to detect transverse cracks.

Project Management Institute. Kingdom of Saudi Arabia

3.2. ADDITIONAL FINDINGS

Micrographs showed crack initiation along the fusion boundary, with clear indications of copper segregation. These were not captured in RT due to its inherent resolution limitations in detecting micro-level discontinuities, especially transverse to the beam path.

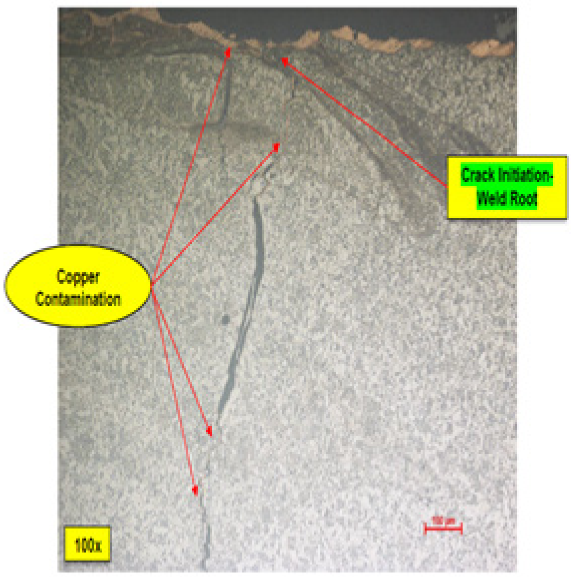

element

Micro Photograph

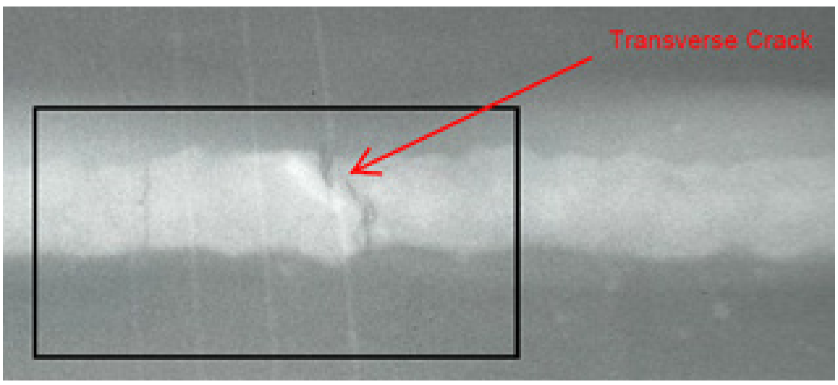
Weld Joint # 781

Total Number of Crack Observed: 18
Sample Length: 50 mm
Crack Depth (Max): 8.02 mm
Crack Depth (Min): 0.15 mm

Crack No.	Depth
Crack # 1	306.69 μm = 0.30 mm
Crack # 2	236.38 μm = 0.23 mm
Crack # 3	844.20 μm = 0.84 mm
Crack # 4	911.65 μm = 0.91 mm
Crack # 5	363.61 μm = 0.36 mm
Crack # 6	869.50 μm = 0.86 mm
Crack # 7	391.01 μm = 0.39 mm
Crack # 8	897.95 μm = 0.89 mm
Crack # 9	374.15 μm = 0.37 mm
Crack # 10	889.52 μm = 0.88 mm
Crack # 11	895.84 μm = 0.89 mm
Crack # 12	2,394.54 μm = 2.39 mm
Crack # 13	156.18 μm = 0.15 mm
Crack # 14	154.60 μm = 0.15 mm
Crack # 15	584.93 μm = 0.58 mm
Crack # 16	0.85 mm
Crack # 17	1.96 mm
Crack # 18	8.02 mm



Picture C: list of multiple micro cracks in on location



Picture E: RT film showing the defect

3.3. PROCESS DEVIATION

The Welding Procedure Specification (WPS) had not been adequately enforced. Operators reduced travel speed, deviating from WPS parameters, which increased heat input and exacerbated copper melting and contamination. This deviation is a well-documented factor in increasing susceptibility to hot cracking (Ref: AWS D1.1, Annex K).

4. CORRECTIVE ACTIONS

4.1. IMMEDIATE REMEDIATION

The two defective joints were removed. Surrounding joints (10 preceding and 10 succeeding) were re-inspected using RT. Thirteen additional cracked joints were identified, totaling 15, all of which were cut out and rewelded.

4.2. PROCESS IMPROVEMENTS

Welding control procedures were reinforced by locking travel speed settings and introducing a process checklist to ensure consistency and quality. The Automated Ultrasonic Testing (AUT) procedure was revised to include transverse scanning channels to improve crack detection capabilities.

An Engineering Critical Assessment (ECA) was conducted, establishing a detection threshold for cracks up to 1.0 mm in depth. Based on this assessment, the contractor DAC and NDT service provider Sievert Arabia are required to revalidate the AUT procedure. This revalidation involves incorporating additional transverse scanning channels on both the inner diameter (ID) and outer diameter (OD) for all pipe sizes to enable detection of transverse cracks in weld joints.
However, the updated AUT technique has a known limitation, it cannot detect transverse cracks smaller than 0.5 mm in depth. Despite this limitation, the procedure aligns with the ECA's threshold, which only mandates detection of cracks equal to or greater than 1.0 mm

4.3. QUALITY ASSURANCE MEASURES

Workshops and inspections were conducted to ensure compliance with best practices. Regular maintenance of copper backing shoes was mandated to prevent contamination. Additionally, a quality awareness session focused on the mechanized welding process was held for all relevant personnel, including welding operators/welders, pipe fitters, welding foremen and supervisors, site engineers, and QC inspectors.

4.4. VALIDATION AND TESTING

The contractor welded 133 weld joints of 16 & ”40 ,”24” (WT 6.35mm & 15.88 mm) with presence SAPID as the hold point. All welds were %100 inspected by old AUT and RT and some weld joints were examined by revised AUT procedure and found no cracks. Furthermore, when the root and hot pass are completed, Contractor QC and SAPID have visually verified the internal line-up clamp shoes for any evidence of copper deterioration using the inspection checklist that has been developed and approved by CSD/SAPMT/SAPID.

4.5. RISK MANAGEMENT

High-heat input welds were reclassified as high-risk and scheduled for re-inspection using updated NDT methods before project closure.

5. LESSONS LEARNED

1. AUT Technique Limitations:

Highlighted the importance of regularly validating and enhancing inspection technologies to ensure defect detection reliability.

2. Process Control Compliance:

Reinforced the critical need for strict adherence to approved Welding Procedure Specifications (WPS) to maintain weld quality.

3. Copper Material Management:
Stressed the necessity of controlling copper-based components under rigorous quality protocols to prevent contamination-related defects.

4. Proactive Risk Mitigation:
Demonstrated that early reinspection of high-risk welds is effective in preventing widespread quality issues.

6. CONCLUSION

The case study offered valuable insights into the inherent limitations of Automated Ultrasonic Testing (AUT) methods, as well as the systemic risks associated with process deviations during mechanized welding operations. It highlighted how such deviations, if left unaddressed, could compromise the structural integrity of pipeline systems on a large scale.

By adopting advanced inspection techniques, strictly enforcing procedural compliance, and implementing proactive Quality Assurance and Quality Control (QA/QC) measures, the project team successfully mitigated a potentially significant integrity issue. These actions underscore the critical importance of ongoing validation of Non-Destructive Testing (NDT) methodologies and the need for robust process control mechanisms in high-stakes pipeline construction projects.

Furthermore, in addition to the above measures, consideration should be given to substituting the internal clamp copper shoe material with a more suitable alternative. This substitution should be supported through consultation with the Construction Support Department (CSD), and the revised process must undergo formal approval for use in mechanized Gas Metal Arc Welding (GMAW) applications. This change, once validated, could further enhance weld quality and reduce the risk of process-induced defects.

Project Management Institute. Kingdom of Saudi Arabia

REFERENCES

1. ASM Handbook, Volume 11: Failure Analysis and Prevention. ASM International.
2. API 1104: Welding of Pipelines and Related Facilities.
3. ASME B31.8: Gas Transmission and Distribution Piping Systems.
4. AWS D1.1: Structural Welding Code – Steel.
5. NDT Handbook, Volume 7: Ultrasonic Testing, American Society for Nondestructive Testing (ASNT).
6. SAES-W-012 - Welding Requirements for Pipelines