

QUALITY ASSURANCE AND INSPECTION PRACTICES IN SHIPBUILDING: AN INDUSTRIAL CASE STUDY

Marcelo de Oliveira Predes¹

Received 27.05.2026.

Revised 13.08.2026.

Accepted 08.09.2026.

Keywords:

Quality assurance; Quality control; Shipbuilding; Traceability; Welding inspection; Non-destructive testing.

ABSTRACT

This paper analyzes the application of Quality Assurance and Quality Control practices during the construction of an aluminum vessel through an industrial case study. The investigation focuses on the integration of material traceability, documentary verification, visual inspection and liquid penetrant testing as complementary mechanisms for ensuring manufacturing conformity. The research adopted a qualitative case study methodology based on the observation of quality inspection activities performed during the construction process, supported by technical documentation and inspection records. Based on these findings, an integrated quality management framework is proposed, combining inspection planning, material traceability, quality documentation, non-destructive testing, and continuous improvement within a unified production workflow. The results demonstrate that the systematic integration of documentary control, traceability and non-destructive testing provides objective evidence of conformity throughout production, strengthening structural reliability and supporting future maintenance and auditing activities. The study concludes that effective quality management in shipbuilding depends not only on inspection techniques but also on the implementation of preventive quality assurance practices that integrate engineering, production and inspection throughout the manufacturing process. Furthermore, the structured generation of quality records establishes a foundation for future Quality 4.0 initiatives, including digital traceability and data-driven quality management systems.



© 2026 Published by Faculty of Engineering

1. INTRODUCTION

For different vessels to meet the safety and performance requirements imposed by classification societies, rigorous quality control during the construction process is essential. Such compliance is not only tied to the quality of the materials used, such as metal plates, piping systems, and equipment, but also to inspection, traceability, and control processes: actions that ensure all production stages comply with established regulatory requirements.

The use of aluminum alloys in shipbuilding has expanded in recent decades due to their mechanical properties, high corrosion resistance, and structural weight reduction, factors that foster increased operational efficiency for vessels. However, these benefits also demand greater care during the manufacturing process, particularly regarding welding control, material traceability, and compliance verification during construction. Quality Assurance (QA) and Quality Control (QC) play complementary roles in this scenario. While QA

¹ Corresponding author: Marcelo de Oliveira Predes
Email: marcelo.o.predes@gmail.com

establishes the necessary processes, procedures, and requirements to prevent non-conformities, QC focuses on the systematic verification of products and processes through inspections, testing, and records. The integration of these practices contributes to risk mitigation and enhances the reliability of the final product.

Although numerous studies on welding, non-destructive testing (NDT), material selection, and manufacturing processes in the naval industry can be found in the literature, there is a limited number of works comprehensively describing how QA practices, traceability, and inspection are effectively applied in real vessel construction projects. Industrial case studies can help bridge this gap by presenting practical experiences and lessons learned that can be adapted to similar undertakings.

It is within this context that this work aims to analyze, through an industrial case study, the main quality assurance and traceability practices employed during the construction of an aluminum vessel, discussing their contribution to product compliance and manufacturing activity control.

2. LITERATURE OVERVIEW

2.1 Quality assurance and quality control

The complexity of industrial processes, which must meet stringent compliance requirements, has made quality management a strategic element in various engineering sectors. In the shipbuilding industry, quality ceases to be merely a contractual requirement and becomes a decisive factor for structural integrity, operational safety, and vessel performance throughout its lifecycle. Furthermore, recent studies demonstrate that Quality Management (QM) acts as a compulsory requirement for organizational effectiveness, working synergistically with knowledge management and corporate culture (Mas-Machuca et al., 2018; Sultanova et al., 2024).

Within this scope, the concepts of QA and QC gain prominence as they perform distinct functions within a QM system. According to ISO 9000:2015 (ISO, 2015a), QA encompasses the set of planned and systematic activities intended to provide confidence that quality requirements will be fulfilled. On the other hand, QC focuses on verifying product, process, or service compliance through inspections, measurements, testing, and other assessment activities. This distinction is also emphasized by the Certified Quality Inspector Handbook, which presents inspection as an integral element of the QM system responsible for obtaining objective evidence of product and process conformity (ASQ, 2020).

According to Feigenbaum (1991), quality must be present at all stages of the production process, ranging from initial planning to final delivery, meaning it is not limited to final inspections alone. Similarly, Juran (1999)

highlights that quality is the outcome of a structured management process grounded in planning, control, and continuous improvement, thereby reinforcing the preventive nature of QA. Contemporary perspectives build upon these principles through Industrial and Manufacturing Engineering (IME) tools and Quality 4.0 paradigms, integrating quality management systems with digital platforms, process engineering, and sustainable practices in high-tech manufacturing (Shabaltina et al., 2026).

It is increasingly evident that integrating QA and QC practices contributes significantly to reducing rework, minimizing non-conformities, and increasing product reliability, especially in highly complex industrial environments. In such settings, activities involving inspection planning, the development of Inspection and Test Plans (ITPs), material traceability, special process qualification, and adequate document control enable compliance with technical requirements throughout manufacturing (ASQ, 2020). Returning to the specific case of shipbuilding, these practices become even more critical due to the variety of materials used in production and the diversity of manufacturing activities, such as welding and assembly of components. Thus, QA provides the preventive framework for quality management, while QC acts as the compliance verification mechanism at each stage of the construction process.

2.2 Quality inspection and traceability in shipbuilding

As mentioned, quality inspection constitutes one of the primary mechanisms to ensure that technical and regulatory requirements are met throughout naval construction. Unlike final product inspection, the currently adopted approach prioritizes continuous monitoring of the manufacturing process, allowing for the early identification of deviations and reducing costs associated with rework, waste, and delays (Juran, 1999; ISO, 2015b). In other words, inspection activities range from receiving raw materials to final vessel sea trials, including dimensional inspections, welding control, non-destructive testing, functional tests, and document verification. In this context, classification societies establish requirements for inspection planning, examination and testing activities, material certification, construction records, and survey procedures throughout vessel construction (RINA, 2017).

The traceability of materials used in construction is a critical element, as it enables linking each component, material, or activity executed back to its respective manufacturing, inspection, and approval history. According to Silva and Gasparotto (2020), traceability systems allow for the rapid identification of the root cause of non-conformities, facilitating corrective actions and contributing to reduced operational losses. Broadly defined across industrial sectors, traceability acts as a

critical risk management tool that allows for tracking components from origin to final assembly, transitioning from traditional paper-based methods to comprehensive digital frameworks (Schuitemaker & Xu, 2020).

Recently, literature has associated traceability systems with Industry 4.0 digital technologies. Nozawa et al. (2025) demonstrate that integrating information systems with digital logging platforms significantly enhances data reliability, process transparency, and auditability, generating gains in information accuracy and reducing logistical losses. In naval construction specifically, digital transformation enables automated defect detection and advanced defect traceability across sub-assemblies, allowing quality managers to track the origin and evolution of structural issues to ensure structural integrity (Arcano-Bea et al., 2025). Regardless of the technology employed, one must keep in mind the main goal of traceability: ensuring that every step of the process can be verified, audited, and reconstructed whenever necessary.

2.3 Change management and learning cycle in the inspection process

To ensure that document control and traceability do not become static records, the information collected during inspections must feed back into the production system. In this scenario, the inspection process shifts from being a merely reactive activity to becoming part of a continuous learning cycle, associating knowledge management with engineering change management (Kukulies et al., 2016).

In shipbuilding practice, this flow consolidates when non-conformity reports, such as weld discontinuities or dimensional deviations during block erection, feed directly into root-cause analysis. Evidence collected from the shop floor (Chiaverini, 2014; De Luca, 2014) begins to record failure history and acts as input for planning subsequent subassemblies and vessels. Thus, knowledge generated during execution is formalized through updates to quality control plans, mitigating error recurrence and rework costs (Kukulies et al., 2016).

Recent studies indicate that the effectiveness of this learning process depends not only on corrective actions but also on the capability of manufacturing systems to transform inspection results into actionable knowledge for production planning. In the shipbuilding industry, production-cycle optimization has been associated with the systematic identification of non-value-added activities, process mapping, and continuous monitoring of manufacturing performance, enabling quality information to support operational improvements rather than merely documenting completed inspections (Jebbor et al., 2023). More recently, the evolution toward Quality 4.0 has expanded this concept by incorporating digital traceability, real-time monitoring, and data-driven quality management. Quet al. (2025) proposed a closed-loop feedback mechanism in which inspection data are

continuously reused to support defect prediction, adaptive quality optimization, and continuous process improvement throughout the manufacturing lifecycle.

Consolidating this learning cycle requires coordination among inspector technical skills, well-defined organizational processes, and the use of technological tools for data recording (Andreucci, 2010). Integrating these elements ensures that field data serves both internal process improvement and proof of compliance with acceptance criteria and classification requirements for naval vessel construction (RINA, 2017).

2.4 Quality 4.0 and digital transformation of quality management

Recent advances in Industry 4.0 have significantly influenced quality management by incorporating digital technologies into manufacturing systems. Rather than replacing traditional QA and QC practices, Industry 4.0 provides the technological infrastructure that enables greater connectivity between production processes, data acquisition, and decision-making, while maintaining quality improvement as a central competitive objective (Bekmurzaeva & Kovalev, 2023). Within this context, the concept of Quality 4.0 has emerged as the application of Industry 4.0 technologies to quality management. According to Escobar et al. (2021), Quality 4.0 builds upon the statistical and managerial foundations of previous quality philosophies while incorporating industrial big data, the Industrial Internet of Things (IIoT), and artificial intelligence to support empirical learning, real-time data analysis, defect prediction, and improved decision-making throughout manufacturing processes.

From an implementation perspective, digital quality management increasingly relies on integrated platforms capable of consolidating production data, inspection records, and process information into a unified environment. Filz et al. (2024) argue that such platforms provide a holistic view of process and product interactions across manufacturing systems, enabling data-driven quality planning, proactive interventions, and continuous process improvement rather than isolated quality inspections. Although the industrial case presented in this study is based on conventional QA and QC practices, its inspection workflow, document management, and material traceability procedures are fully compatible with future Quality 4.0 initiatives. Likewise, Carvalho et al. (2021) emphasize that Industry 4.0 technologies can be associated with established quality management practices, demonstrating how digital tools may support activities such as process management, information analysis, quality inspection, and continuous improvement. Consequently, the systematic generation of inspection records described in this case study represents a suitable foundation for future digital traceability and data-driven quality management in shipbuilding.

3. METHODOLOGY

This work is characterized as qualitative research conducted through an industrial case study applied to shipbuilding. According to Yin (2018), case study methodology is suitable for investigating contemporary phenomena within their real-life context, particularly when the objective is to understand the interaction between technical, organizational, and operational aspects involved in a given process. The methodological approach also supports the development of an integrated quality management framework derived from observed industrial practices.

The analyzed process corresponds to the application of QA and QC practices during the construction of aluminum-hull vessels. The study aimed to evaluate how activities related to document control, material traceability, manufacturing monitoring, inspection planning, non-destructive testing, and quality records contribute to ensuring compliance with applicable technical and normative requirements, as well as to develop an integrated quality management framework describing the interaction among these activities throughout vessel construction.

The research was conducted by analysing technical records and evidence obtained during quality monitoring activities in naval construction processes. Documents related to manufacturing materials, inspection records, photographic evidence of construction stages, and NDT results applied to welded joints were considered. The analysis of these elements allowed for an evaluation not only of the inspection results according to established requirements but also of the role these activities play within an integrated quality assurance system.

To achieve this, different stages of the construction process were analysed, starting with the verification of

received materials (such as mill test reports) focusing on the identification, certification, and traceability of metal plates used in the vessel structure. Subsequently, manufacturing control activities were analyzed, particularly those related to the welding process, notably NDTs such as visual inspection of joints and liquid penetrant testing to identify potential surface discontinuities. The data collected were analyzed considering three main aspects:

- The capability of traceability mechanisms to ensure the identification and history of materials used;
- The contribution of inspection activities to verifying the compliance of production processes;
- The generation of objective records capable of proving adherence to quality requirements throughout construction.

Thus, the adopted methodology sought to analyze quality inspection not as an isolated failure-detection activity, but as an integral part of a broader quality assurance system in which procedures, records, technical evidence, and traceability information contribute to vessel reliability, continuous process improvement, and the development of an integrated quality management framework applicable to shipbuilding and related manufacturing industries.

4. CASE STUDY

4.1 industrial context and construction process

The case study was developed by monitoring quality control activities during the construction of small aluminum-alloy vessels. The analyzed construction process involved various manufacturing stages, from receiving and preparing materials to structural assembly and welded joint inspection.

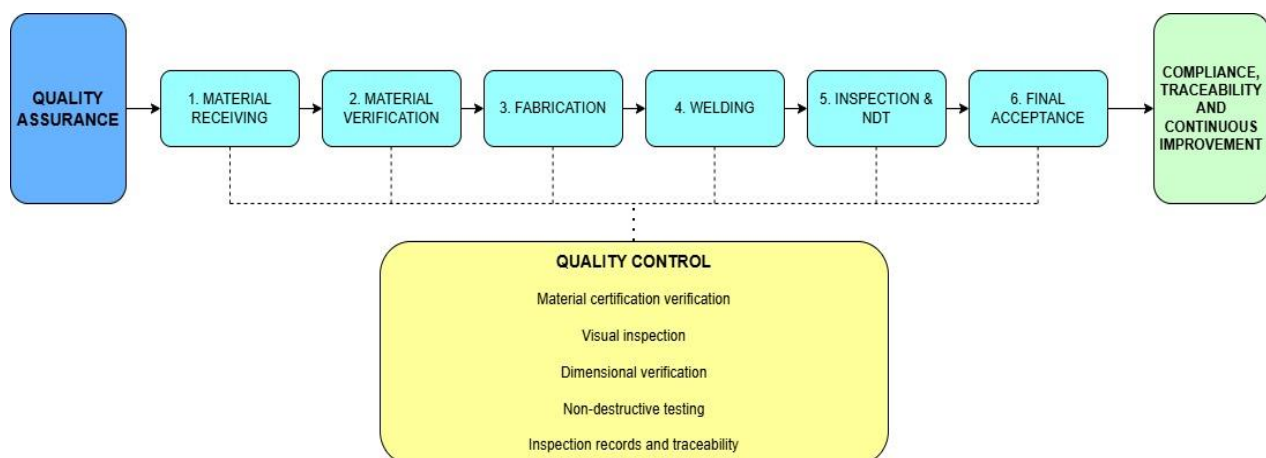


Figure 1. Conceptual structure of QA and QC integration during the vessel construction process.

Source: developed by the author

In this case, using aluminum alloys for the vessel's hull structure demanded special attention to manufacturing processes, mainly due to the metallurgical characteristics of the material and requirements for welded joints. Therefore, quality monitoring was structured to encompass document verification of raw materials, manufacturing process inspections, and the creation of technical records demonstrating the compliance of executed activities. Figure 1 presents a simplified conceptual structure of how main quality activities are integrated during the construction process.

4.2 quality assurance practices and material traceability

One of the first steps in the quality assurance process consisted of document verification for materials used in construction. This activity aimed to ensure that the materials received met design requirements and remained traceable throughout the construction process. For aluminum plates used in the hull structure, certificates provided by the manufacturer, known as Mill Test Certificates (MTC) or Mill Test Reports (MTR), were analyzed. These documents serve as critical quality records, containing details on material identification, chemical composition, mechanical properties, dimensions, and heat/batch numbers.

Material traceability establishes a direct link between a component on the vessel and its manufacturing and inspection records from the supplier. This point is essential in highly complex industrial processes because it allows for investigating deviations, conducting audits, and proving compliance with specifications. Figure 2 shows an example of identification and documentation associated with an aluminum plate used in naval applications, highlighting key traceability information.

MILL'S TEST CERTIFICATE

No. [REDACTED]

产品 Product	铝板 Plate	订货单位 Customer	[REDACTED]	订单号 Order No.	MGHY865
批号 Lot No.	189# [REDACTED]	合金状态 Alloy&Temper	5083H321	规格(mm) Dimension	7x2000x6000
箱号 Box No.	[REDACTED]	张数 PCS	39	净重 (kg) N.T.	8811

Figure 2. Example of information used for material traceability

Source: Adapted from Aluminum Sheet Plate (n.d.)

In addition to material documentation, quality assurance involves maintaining records generated during fabrication. Thus, certificates, inspection reports, and test results form a body of technical evidence accompanying the product throughout its construction.

4.3 In-process quality control activities

Following material verification, in-process quality control activities were monitored during structural fabrication. Among these activities, inspections of

welded joints were prominent, as welding is considered critical to the structural integrity of aluminum vessels.

Weld inspection began with visual testing (VT), used to identify surface discontinuities and assess general weld bead characteristics. Parameters such as uniformity, continuity, surface finish, and indications of defects (e.g., porosity, cracks, undercut, or geometric irregularities) were examined. Subsequently, selected welded joints underwent liquid penetrant testing. This NDT method was selected for its capability to identify surface-breaking discontinuities, serving as a complementary tool for weld quality verification.

The test followed a specific procedure comprising surface preparation, penetrant application, excess penetrant removal, developer application, and indication evaluation. The use of NDT represents a vital quality control practice, as it enables structural evaluation without compromising component usability. The records generated during these activities, including formal reports and photographic evidence, provided objective proof of construction process conformity. Consequently, performed inspections acted not merely as defect detection steps, but as integral components of the quality assurance system applied to the vessel's construction.

4.4 quality documentation flow

Beyond the inspection activities themselves, the effectiveness of the QA system was found to depend directly on the organization and integration of the records generated throughout the manufacturing process. Each stage of construction produces specific documents that, when analyzed collectively, provide a comprehensive manufacturing history of the vessel, allowing objective demonstration of the conformity of the materials used, the manufacturing processes performed, and the inspections carried out.

In the industrial case analyzed, this documentation flow begins during the material receiving stage, when the manufacturer's MTCs are verified. These certificates provide essential information regarding material identification, chemical composition, mechanical properties, and production batch numbers. During fabrication, additional records are generated from quality control activities, including visual inspection reports, liquid penetrant testing reports, and photographic records of welded joints. It is important to note that these documents do not constitute isolated records but rather complementary pieces of evidence that make it possible to reconstruct the complete manufacturing history of a specific structural component. Consequently, each structural element can be traced back to its original material, the corresponding manufacturing process, and the inspection results obtained throughout production. From a Quality Assurance perspective, this integrated documentation system represents one of the primary mechanisms for demonstrating compliance with

technical and regulatory requirements to the various stakeholders involved in the project, particularly clients, classification societies, and internal auditors. Furthermore, maintaining these records in an organized manner facilitates future maintenance activities, engineering modifications, failure investigations, and

technical assessments throughout the vessel's service life. Figure 3 presents a simplified representation of the quality documentation flow observed during the case study, highlighting the relationship between the main manufacturing activities, inspection procedures, and the generation of quality records.

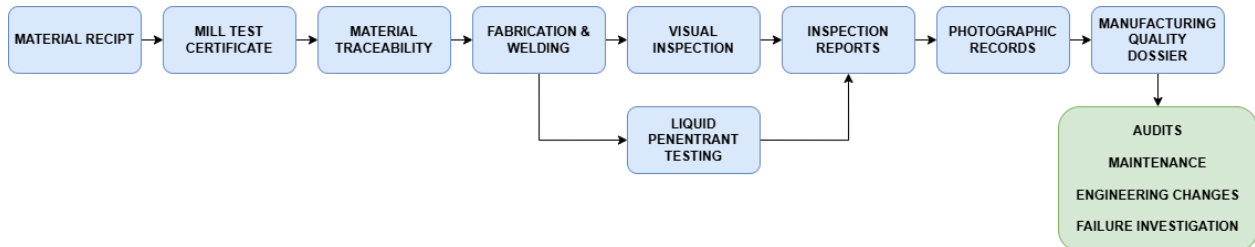


Figure 3. Quality documentation flow throughout the manufacturing process
Source: developed by the author

5. RESULTS AND DISCUSSION

5.1 visual inspection of welded joints

Upon completing the planned welding operations on the evaluated structures, visual testing of welded joints was performed in accordance with the inspection plan. Although relatively simple, this activity is of paramount

importance and serves as the primary QC checkpoint for weld compliance before conducting complementary NDTs. The inspection aimed to identify surface discontinuities that could compromise structural integrity, such as cracks, porosity, undercut, lack of apparent fusion, and geometric irregularities in the weld bead (Figure 4). The assessment also addressed bead continuity, profile uniformity, and surface finish

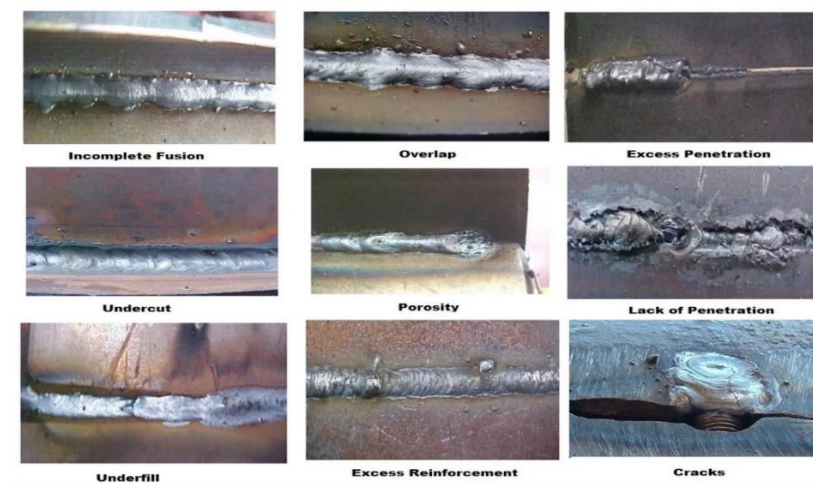


Figure 4. Common weld bead defects.
Source: adapted from Eabel (2025)

Inspections revealed no surface discontinuities that would warrant repairs or rework (the observed weld bead pattern is illustrated in Figure 5). The beads exhibited continuity, geometry compatible with the manufacturing process, and satisfactory surface finish, meeting all criteria required to proceed to subsequent inspection stages. Beyond defect identification, visual inspection served as a crucial process control point, yielding objective evidence that welded joints met minimum standards for NDT clearance.

Finally, Table 1 summarizes the key parameters evaluated during this phase.



Figure 5. Welded joint image at the internal region of the transom
Source: author

Table 1. Summary of visual inspection for welded joints.

Evaluated aspect	Observed result
Bead continuity	Conforming
Geometric uniformity	Conforming
Surface finish	Conforming
Surface cracks	None observed
Porosity	None observed
Undercut	None observed
Clearance for NDT	Approved

Source: developed by the author

5.2 liquid penetrant testing

Following VT approval, selected joints underwent liquid penetrant testing as a complementary method to assess surface integrity. Testing followed standard procedures: surface cleaning, penetrant application, excess removal, developer application, and visual inspection of indications. Figure 6 illustrates one of the records captured during testing.



Figure 6. Liquid penetrant testing on fuel tank weld bead

Source: author

5.3 integration between quality assurance and quality control

The results demonstrate that QA and QC operate as complementary components of an integrated quality management system throughout naval vessel construction. While QA establishes inspection planning, procedures, acceptance criteria, documentation requirements, and material traceability before and during production, QC provides objective evidence of conformity through inspections, measurements, and non-destructive testing performed throughout manufacturing. As illustrated in Figure 7, the quality management framework observed in the case study integrates material receipt, documentation and traceability, fabrication and welding, inspection activities, quality records, and the manufacturing quality dossier into a continuous quality assurance and quality control process. Rather than representing isolated inspection steps, the framework establishes successive verification points that reduce the likelihood of non-conformity propagation while ensuring complete traceability of materials, inspection results, and manufacturing records.

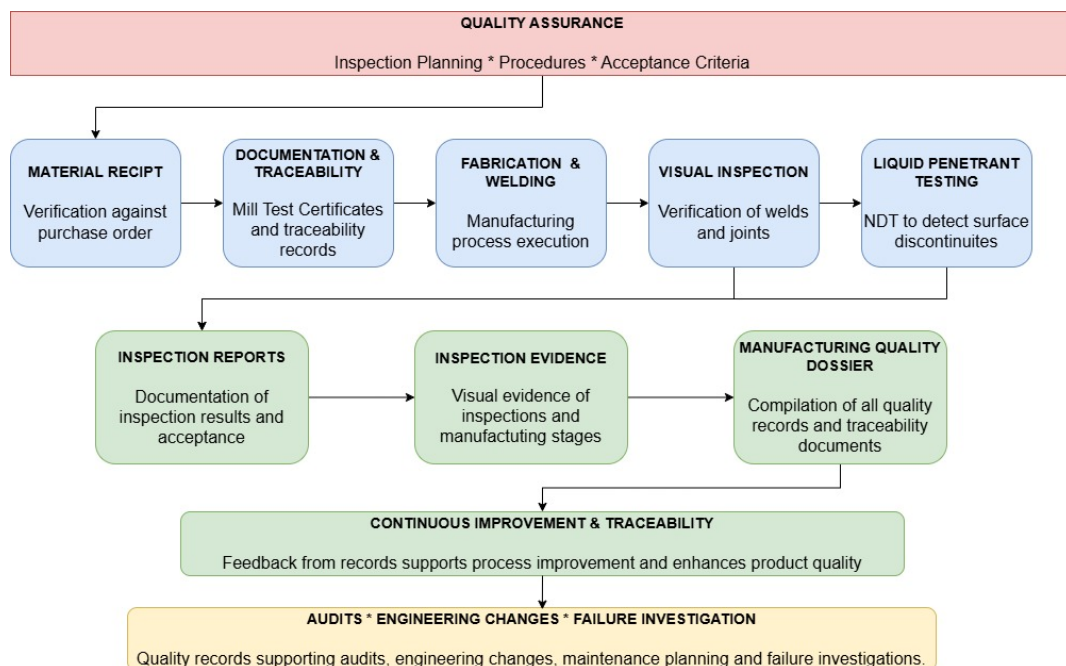


Figure 7. Integrated quality management framework observed in the shipbuilding case study

Source: developed by the author

Passing visual inspection constituted a prerequisite for liquid penetrant testing, while inspection reports and photographic records documented the conformity of welded joints and other inspected components. The resulting Manufacturing Quality Dossier consolidated the technical evidence required for customer acceptance and compliance with Classification Society requirements (such as RINA, BV, and others). Beyond product acceptance, the quality records generated throughout the manufacturing process become valuable engineering assets. Inspection reports, photographs, material certificates, and traceability documentation support future audits, maintenance planning, engineering modifications, and failure investigations, enabling inspection data to contribute to organizational learning and continuous improvement. This integration transforms inspection from a verification activity into a management tool that supports quality assurance across the entire production lifecycle.

Although this study focused on aluminum vessel construction, the proposed quality management framework can be applied to other industrial sectors involving special manufacturing processes, particularly where traceability, documented inspections, and non-destructive testing are essential to product conformity. Furthermore, the structured generation of inspection records and traceability information provides a solid foundation for future Quality 4.0 initiatives, including digital traceability, integrated quality information systems, and data-driven continuous improvement.

5.4 practical quality performance indicators

While the previous section presented the integrated QA/QC framework adopted during vessel construction, its effectiveness can also be evaluated through practical quality performance indicators commonly applied in industrial manufacturing. During vessel construction, quality management extends beyond product acceptance by continuously monitoring manufacturing activities capable of generating non-conformities and rework. Typical quality events identified during vessel construction include the receipt of materials that do not fully comply with procurement specifications, incomplete material traceability identification, weld discontinuities requiring repair after visual or liquid penetrant inspection, dimensional deviations in fabricated structural components, and inconsistencies between manufacturing documentation and inspection records. Such events require additional inspections, corrective actions, documentation updates, and, in some cases, manufacturing rework, directly affecting production efficiency and schedule performance.

Based on these activities, several quality performance indicators can be adopted to objectively evaluate the effectiveness of the integrated quality management system. Rather than serving solely as production statistics, these indicators provide objective evidence of process performance, support root-cause analysis, and facilitate preventive actions and continuous improvement. Typical examples applicable to the proposed framework are presented in Table 2.

Table 2. Summary of visual inspection for welded joints.

Indicator	Purpose
Non-Conformity Reports (NCRs)	Monitor the occurrence of quality deviations throughout manufacturing.
Rework Rate	Evaluate the frequency of repair and rework activities resulting from detected non-conformities.
First-pass inspection acceptance rate	Measure the percentage of inspected items accepted without requiring repair or rework.
Material traceability compliance	Verify the completeness of material identification and certification records throughout manufacturing.
Recurrence of non-conformities	Identify repetitive failures requiring root-cause analysis and preventive actions.
Open inspection findings	Monitor pending quality issues awaiting corrective action and formal closure.

Source: developed by the author.

Although quantitative production records were not available for this case study, the proposed indicators are fully compatible with the integrated quality management framework presented in Figure 7. Since inspection reports, material certificates, non-destructive testing records, and traceability documentation are systematically generated throughout the manufacturing process, these data provide a structured basis for future performance monitoring. Consequently, the proposed framework establishes the necessary foundation for future implementation of digital traceability, integrated quality information systems, and data-driven continuous

improvement initiatives aligned with Quality 4.0 principles.

The proposed framework also demonstrates a natural evolution path toward Quality 4.0 environments. As inspection data, material certificates, NDT reports, and traceability records are progressively digitized, the same workflow can support integrated quality information systems capable of monitoring process performance in real time. Consequently, the proposed methodology establishes a practical foundation for future applications involving digital traceability, data-driven quality control, predictive quality analytics, and intelligent

manufacturing systems without requiring significant changes to the underlying QA/QC procedures.

6. CONCLUSIONS

This study analyzed, through an industrial case study, the application of QA and QC practices during aluminum vessel construction and proposed an integrated quality management framework that combines inspection planning, material traceability, quality documentation, non-destructive testing, and continuous improvement within a single production workflow. Results showed that vessel quality does not depend solely on end-of-line inspections, but rather on a structured set of planned activities accompanying all production stages. Within this framework, document verification of raw materials, inspection planning, systematic execution of visual and liquid penetrant testing, and logging generated evidence serve as complementary components of a QM system. The proposed framework represents the main scientific contribution of this study by consolidating these quality management activities into a structured workflow that can support both practical implementation and future research in industrial quality engineering.

The study also demonstrated that traceability plays a fundamental role in shipbuilding by connecting materials, processes, and inspection outcomes to technical records. Beyond satisfying Classification Society requirements and applicable standards, this information forms the vessel's technical history, supporting maintenance, engineering modifications, audits, and failure investigations throughout the asset's lifecycle. For instance, investigating a potential structural failure might involve tracing hull plates from fabrication back to the mill supplier.

Another relevant aspect observed is the preventive nature of QA. While QC identifies product compliance through tests and inspections, QA proactively establishes procedures, acceptance criteria, and control mechanisms to minimize non-conformities and enhance manufacturing reliability. This combination reinforces that system effectiveness relies on cross-functional integration among engineering, production, and inspection departments.

Finally, although this research focused on aluminum shipbuilding, the presented practices hold application potential for diverse industrial sectors using special manufacturing processes, particularly those requiring stringent document control, material traceability, and quality inspection. Furthermore, the proposed framework establishes a practical pathway toward Quality 4.0 implementation. As inspection records and traceability information become progressively digitalized, the same workflow can support digital traceability, integrated quality information systems, data-driven quality control, and intelligent manufacturing environments without altering the underlying QA and QC principles.

As a research limitation, this study was based on a single industrial case study focused on specific construction activities, omitting other control mechanisms such as dimensional inspection, ultrasonic or radiographic testing, internal audits, vendor qualification, and quality key performance indicators (KPIs). Future studies should expand this investigation to different shipyards and vessel types, incorporating quantitative quality KPIs, Cost Of Poor Quality (COPQ), Statistical Process Control (SPC) tools, and digital technologies applied to traceability and integrated inspection management. Such studies will contribute to developing more comprehensive quality management models for the shipbuilding industry.

References:

- American Society for Quality [ASQ] (2020). *The certified quality inspector handbook* (3rd ed.). Milwaukee, WI: ASQ Quality Press.
- Aluminum Sheet Plate. (n.d.). *Aluminum 5083 plate mill test certificate*. Retrieved January 22, 2026, from <https://aluminumsheetplate.com/index.html>
- Andreucci, R. (2010). *Líquidos penetrantes*. Rio de Janeiro, RJ: ABENDI.
- Arcano-Bea, P., Rubiños, M., García-Fischer, A., Zayas-Gato, F., Calvo-Rolle, J. L., & Jove, E. (2025). *Defect detection for enhanced traceability in naval construction*. *Sensors*, 25(4), 1077. doi:10.3390/s25041077
- Bekmurzaeva, R., & Kovalev, G. S. (2023). Industry 4.0: The fourth industrial revolution. *SHS Web of Conferences*, 172, 02011. doi:10.1051/shsconf/202317202011
- Carvalho, A. V., Enrique, D. V., Chouchene, A., & Charrua-Santos, F. (2021). Quality 4.0: An overview. *Procedia Computer Science*, 181, 341–346. doi:10.1016/j.procs.2021.01.176
- Chiaverini, V. (2014). *Tecnologia mecânica: Processos de fabricação e inspeção*. São Paulo, SP: McGraw-Hill.
- Eabel. (2025). *Common welding defects*. Retrieved from <https://www.eabel.com/common-welding-defects/>
- Escobar, C. A., McGovern, M. E., & Morales-Menendez, R. (2021). Quality 4.0: A review of big data challenges in manufacturing. *Journal of Intelligent Manufacturing*, 32, 2319–2334. doi:10.1007/s10845-021-01765-4
- Feigenbaum, A. V. (1991). *Total quality control* (3rd ed.). New York, NY: McGraw-Hill.

- Filz, M.-A., Bosse, J. P., & Herrmann, C. (2024). Digitalization platform for data-driven quality management in multi-stage manufacturing systems. *Journal of Intelligent Manufacturing*, 35, 2699–2718. doi:10.1007/s10845-023-02162-9
- International Organization for Standardization [ISO] (2015a). *Quality management systems — Fundamentals and vocabulary* (ISO Standard No. 9000:2015). Geneva, Switzerland: ISO.
- International Organization for Standardization [ISO] (2015b). *Quality management systems — Requirements* (ISO Standard No. 9001:2015). Geneva, Switzerland: ISO.
- International Organization for Standardization [ISO] (2016). *Non-destructive testing of welds — Visual testing of fusion-welded joints* (ISO Standard No. 17637:2016). Geneva, Switzerland: ISO.
- International Organization for Standardization [ISO] (2021). *Non-destructive testing — Penetrant testing — Part 1: General principles* (ISO Standard No. 3452-1:2021). Geneva, Switzerland: ISO.
- Jebbor, I., Benmamoun, Z., & Hachimi, H. (2023). Optimizing manufacturing cycles to improve production: Application in the traditional shipyard industry. *Processes*, 11(11), 3136. doi:10.3390/pr11113136
- Juran, J. M., & Godfrey, A. B. (Eds.). (1999). *Juran's quality handbook* (5th ed.). New York, NY: McGraw-Hill.
- Kukulies, J., Falk, B., & Schmitt, R. (2016). A holistic approach for planning and adapting quality inspection processes based on engineering change and knowledge management. *Procedia CIRP*, 52, 240–245. doi:10.1016/j.procir.2016.07.037
- Mas-Machuca, M., Akhmedova, A., & Marimon, F. (2018). Quality management: A compulsory requirement to achieve effectiveness. *Total Quality Management & Business Excellence*, 32(13–14), 1–20. doi:10.1080/14783363.2018.1548275
- Nozawa, E. H., Souza Neto, W. B., dos Santos Trindade, L. C., Martins, P. R. O., & Santiago, S. B. (2025). Rastreabilidade de materiais com blockchain: Um estudo de caso em uma indústria de fitas. *Revista de Gestão Social e Ambiental*, 19(8), 1–11. doi:10.24857/rgsa.v19n8-002
- Qu, Y., Chu, X., & Cheng, S. (2025). Closed-loop feedback mechanism for recommending quality optimization solutions for smart manufacturing systems. In *Proceedings of the 5th International Conference on Control and Intelligent Robotics (ICCIR 2025)* (pp. 219–223). ACM. doi:10.1145/3757940.3757976
- Registro Italiano Navale [RINA] (2017). Rules for the classification of naval ships. Genoa, Italy: RINA Services S.p.A.
- Schuitemaker, R., & Xu, X. (2020). Product traceability in manufacturing: A technical review. *Procedia CIRP*, 93, 700–705. doi:10.1016/j.procir.2020.04.078
- Shabaltina, L. V., Abrosimova, V. V., Sydykov, B. T., Zemlyacheva, E. A., & Martirosyan, T. S. (2026). Industrial and manufacturing engineering as the basis of quality management in high-tech production with the implementation of green and social innovations. *International Journal for Quality Research*, 20(2), 529–548. doi:10.24874/IJQR20.02-14
- Silva, A. R., & Gasparotto, A. M. S. (2020). Um estudo sobre rastreabilidade visando ao controle de processos. *Interface Tecnológica*, 17(1), 708–720. doi:10.31510/inf.v17i1.796
- Sultanova, S. M., Ivanova, M. A., Fomenko, N. M., Turebekova, B. O., & Konysbay, A. (2024). Quality management through sustainable hrm based on digital competencies. *International Journal for Quality Research*, 18(4), 991–1004. doi:10.24874/IJQR18.04-05
- Yin, R. K. (2018). *Case study research and applications: Design and methods* (6th ed.). Thousand Oaks, CA: Sage Publications.

Marcelo de Oliveira Predes

Brazilian Navy,
Brasília,
Brazil

marcelo.o.predes@gmail.com

ORCID 009-0001-2189-4088
