

Evaluation of Welding Techniques for Fabricating Corrosion-Resistant Marine Components

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Abstract- The fabrication of corrosion-resistant marine components is essential for improving the durability, safety, and reliability of ships, offshore structures, and marine equipment exposed to aggressive seawater environments. This review evaluates welding techniques used in fabricating marine components, focusing on their influence on corrosion resistance, mechanical properties, weld quality, and fabrication cost. The welding processes examined include gas tungsten arc welding, gas metal arc welding, shielded metal arc welding, flux-cored arc welding, submerged arc welding, and friction stir welding. The review discusses commonly used marine materials, including carbon steel, stainless steel, duplex stainless steel, aluminium alloys, copper-nickel alloys, and nickel-based alloys. It also examines major corrosion mechanisms, such as pitting, crevice, galvanic, intergranular, and stress corrosion cracking. Furthermore, the effects of welding parameters, heat input, filler-metal selection, and microstructural changes on welded-joint performance are highlighted. Corrosion evaluation methods, including immersion testing, salt spray testing, potentiodynamic polarization, and electrochemical impedance spectroscopy, are discussed. The review emphasizes that welding performance depends on material selection, process control, surface preparation, and post-weld treatment. It identifies research gaps concerning standardized comparative testing and long-term seawater exposure. Overall, an integrated assessment of corrosion resistance, mechanical strength, productivity, and lifecycle cost is necessary for selecting suitable welding techniques for reliable marine component fabrication.

Keywords— Welding, Fabricating, Corrosion-Resistant, Marine, Components

I. INTRODUCTION TO MARINE COMPONENTS AND CORROSION IN MARINE ENVIRONMENTS

Marine components are structural and mechanical parts used in ships, offshore platforms, subsea pipelines, ship hulls, propellers, heat exchangers, storage tanks, and other equipment exposed to seawater. These components operate under demanding conditions, including high salinity, dissolved oxygen, moisture, temperature fluctuations, mechanical loading, and biological activity. Consequently, the selection of suitable materials and fabrication techniques is essential for ensuring their structural integrity, durability, and service life. Corrosion is one of the major degradation mechanisms affecting marine engineering materials. In seawater, electrochemical reactions can cause metals to deteriorate, resulting in material loss, surface damage, leakage, and structural failure. Chloride ions are particularly important because they can destabilize the

protective passive film on stainless steel and promote localized corrosion, especially pitting and crevice corrosion (Revie & Uhlig, 2008). Welding is widely used in marine fabrication because it produces permanent joints between metallic components. However, the welding process can alter the microstructure, chemical composition, residual stress distribution, and corrosion behaviour of the base material. The weld metal and heat-affected zone may therefore exhibit different corrosion resistance from the unaffected parent material (Lippold & Kotecki, 2005). The evaluation of welding techniques for fabricating corrosion-resistant marine components requires consideration of both mechanical performance and electrochemical behaviour. A suitable welding process should produce strong, defect-free joints while minimizing detrimental microstructural changes and susceptibility to localized corrosion. This review examines the materials used in marine fabrication, common welding techniques, corrosion mechanisms, welding parameters, testing methods,

and comparative performance of welded components.

II. TYPES AND PROPERTIES OF MATERIALS USED FOR MARINE COMPONENT FABRICATION

The selection of materials is a fundamental consideration in the fabrication of corrosion-resistant marine components. Marine materials must withstand seawater exposure, mechanical loading, erosion, fatigue, and, in some applications, elevated temperatures and pressure. Their performance depends on chemical composition, microstructure, strength, toughness, corrosion resistance, weldability, and maintenance requirements (Francis, 2017; Shifler, 2022). Stainless steels, aluminium alloys, copper-nickel alloys, carbon steels, duplex stainless steels, and nickel-based alloys are among the metallic materials used in marine environments. Each material group offers different advantages, and its suitability depends on the intended application, operating conditions, and fabrication requirements (Davis, 2006; Revie & Uhlig, 2008).

Table 1. Materials used for fabricating marine components and their properties

Material	Important properties	Typical marine applications	Main limitations
Carbon steel	High strength, good availability, relatively low cost	Ship hulls, structural components, offshore platforms, pipelines	Prone to corrosion, requires protective coatings, not suitable for seawater fusion-welding
Austenitic stainless steel	Good general corrosion resistance, ductility, and toughness	Piping, valves, heat exchangers, seawater equipment	Susceptible to stress corrosion cracking, expensive
Duplex stainless steel	High strength and good resistance to pitting and chloride stress corrosion cracking	Offshore piping, seawater systems, pressure vessels, severe environments	Requires careful control of welding heat input and phase balance
Aluminium alloys, especially 5xxx and 6xxx series	Low density, useful strength-to-weight ratio, good marine performance in suitable grades	Ship superstructures, decks, hulls, lightweight structures	Not suitable for fusion welding, requires special techniques
Copper-nickel alloys	Good seawater corrosion resistance and resistance to biofouling	Heat exchangers, condensers, seawater piping	Relatively high cost, difficult to weld
Nickel-based alloys	High resistance to severe corrosion and elevated temperatures in suitable grades	Specialized offshore equipment, chemical processing components	Very expensive, difficult to fabricate

Sources: Davis (2006), Francis (2017), Lippold and Kotecki (2005), Shifler (2022), and Revie and Uhlig (2008).

Table 1 demonstrates that no single material is ideal for every marine application. Carbon steel is often attractive for large structural components because of its strength, availability, and affordability. However, its relatively low resistance to seawater corrosion means that coatings, corrosion allowances, inhibitors, or cathodic protection may be required. Its welded joints must also be assessed for localized corrosion and environmentally assisted cracking (Davis, 2006; Revie & Uhlig, 2008). Austenitic stainless steel offers good corrosion resistance through a chromium-rich passive film. Nevertheless, chloride ions in seawater can cause localized breakdown of this film. Duplex stainless steel provides an attractive alternative for many demanding applications because its ferritic-austenitic microstructure combines high strength with good resistance to localized corrosion. However, unsuitable welding conditions can produce an undesirable phase balance or harmful secondary phases, reducing performance (Lippold & Kotecki, 2005; Mohammed et al., 2017; Verma & Taiwade, 2017). Aluminium alloys are particularly useful where reducing structural weight is important. Their corrosion resistance depends on the alloy composition and exposure conditions, while their welded joints may experience softening, distortion, or defects. Friction stir welding has attracted attention for marine aluminium because it joins

phase balance and pitting resistance, while aluminium alloys allow the comparison of conventional fusion welding with solid-state welding. These materials should not be assessed

using identical acceptance criteria because their metallurgy and corrosion mechanisms differ.

III. FUNDAMENTALS AND CLASSIFICATION OF WELDING TECHNIQUES

Welding is a permanent joining process in which materials are joined using heat, pressure, or a combination of both, with or without filler material. It is extensively used in marine fabrication because ship hulls, offshore structures, pipelines, tanks, and equipment require strong joints capable of withstanding mechanical and environmental loads (Kou, 2003). Welding processes are commonly classified into fusion welding and solid-state welding as shown in figure 1. Fusion welding involves melting the base material at the joint, while solid-state welding joins surfaces without completely melting the base material. Gas tungsten arc welding, gas metal arc welding, shielded metal arc welding, flux-cored arc welding, submerged arc welding, and laser beam welding are examples of fusion processes. Friction stir welding is a prominent solid-state process (Kou, 2003; Messler, 2004). The suitability of a welding technique depends on the material, component thickness, joint design, accessibility, production rate, required weld quality, and operating environment. For corrosion-resistant marine components, the process must also limit contamination, excessive heat input, harmful microstructural changes, and defects that could initiate corrosion (Davis, 2006).

An important distinction is that the welding process alone does not determine corrosion resistance. Filler-metal composition, shielding conditions, joint geometry, surface condition, and welding procedure can be equally important. A technically sound weld may still corrode prematurely if heat tint, embedded contaminants, or unfavourable microstructural features are left untreated (Davis, 2006; Lippold & Kotecki, 2005).



Figure 1: Fundamentals and Classification of Welding Techniques

IV. COMMON WELDING TECHNIQUES USED IN MARINE COMPONENT FABRICATION

Several welding techniques are used to fabricate and repair marine components. Their differences in heat source, deposition rate, shielding, material compatibility, and degree of automation influence the resulting joint quality and corrosion performance.

Table 2: Common welding techniques and their characteristics

Welding technique	Principle	Main advantages	Limitations and marine suitability
Gas Tungsten Arc Welding (GTAW/TIG)	An electric arc forms between a non-consumable tungsten electrode and the workpiece	Good control, clean welds, suitable for thin materials and corrosion-resistant alloys	Relatively slow; requires good shielding and skilled operation
Gas Metal Arc Welding (GMAW/MIG)	A continuously fed consumable wire electrode forms the arc under shielding gas	High productivity, readily automated, suitable for many structural and alloy applications	Sensitive to shielding disruption, surface contamination, and parameter selection

Shielded Metal Arc Welding (SMAW)	An arc forms between a flux-coated consumable electrode and the workpiece	Portable, flexible, useful for repair and field work	Slag removal is required; productivity is lower than many continuous-wire processes
Flux-Cored Arc Welding (FCAW)	A tubular flux-cored wire is used, with or without external shielding gas	High deposition rate, suitable for structural fabrication and certain outdoor applications	Slag, fume, and procedure-control requirements can affect quality
Submerged Arc Welding (SAW)	The arc operates beneath a layer of granular flux	High deposition rate, useful for long, relatively straight welds and thick sections	Restricted access and position; less suitable for many small or complex joints
Laser Beam Welding (LBW)	A concentrated laser beam provides localized heating and melting	High speed, narrow welds, low overall distortion in suitable applications	High equipment cost, joint-fit-up sensitivity, and specialized process control
Friction Stir Welding (FSW)	A rotating tool generates frictional heat and plasticizes material without bulk melting	Useful for suitable aluminium alloys; can reduce fusion-related defects and distortion	Requires tool access and substantial clamping; not equally suitable for every alloy or geometry

Sources: Kou (2003), Messler (2004), Lippold and Kotecki (2005), and Venugopal et al. (2023).

Table 2 and figure 2 shows that the welding processes differ in productivity, precision, accessibility, and their capacity to control the thermal cycle. GTAW is often preferred where clean, carefully controlled welds are required, especially for stainless steel and corrosion-resistant alloys. Its

ability to control heat and filler-metal addition can be advantageous, although the process requires considerable operator skill and may be too slow for large-scale fabrication (Kou, 2003; Lippold & Kotecki, 2005). GMAW is suitable for repetitive and automated fabrication because it uses a continuously fed wire electrode. When its current, voltage, travel speed, shielding gas, and filler material are correctly selected, it can produce sound joints at relatively high production rates. However, inappropriate parameters can cause porosity, incomplete fusion, excessive heat input, or microstructural changes that adversely affect corrosion performance. Studies of duplex stainless steel weldments demonstrate the importance of matching the welding procedure to the alloy's metallurgical requirements (Mohammed et al., 2017; Verma & Taiwade, 2017). SMAW is valuable for marine repair and field fabrication because its equipment is portable and can be used in varied working conditions. Nevertheless, slag removal, electrode handling, and operator-dependent process variation require attention. FCAW and SAW are often attractive for larger structures because they can provide high deposition rates. Their suitability depends on the joint configuration, material grade, welding position, flux or shielding requirements, and the inspection requirements for the finished structure (Kou, 2003; Messler, 2004). Laser beam welding offers a concentrated heat source and can reduce the width of the heat-affected zone in suitable applications. However, its cost and sensitivity to joint fit-up may restrict its use. FSW is particularly relevant to marine aluminium structures because the process avoids bulk melting and can reduce some problems associated with fusion welding. Nevertheless, tool design, rotational speed, travel speed, clamping, and alloy condition remain important factors in achieving defect-free joints (Messler, 2004; Venugopal et al., 2023). The table 2 and figure 2 also indicates why a single universal ranking of welding techniques would be misleading. GTAW may be advantageous for precision work, GMAW for automated fabrication, SMAW for repairs, SAW for long structural seams, and FSW for appropriate aluminium joints. Their corrosion resistance must be confirmed through testing on the

actual alloy, filler-metal combination, and welding procedure under consideration.



Figure 2: Common Welding Techniques Used in Marine Component Fabrication.

V. CORROSION MECHANISMS AFFECTING WELDED MARINE COMPONENTS

Corrosion is the deterioration of a material through chemical or electrochemical interaction with its environment. In marine applications, seawater provides an electrolyte containing chloride ions, dissolved oxygen, and other dissolved species that can accelerate metal degradation. The corrosion behavior (figure 3) of a welded component depends on the alloy composition, surface condition, weld microstructure, residual stress, joint geometry, and exposure conditions (Fontana, 1986; Revie & Uhlig, 2008).



Figure 3: Major Corrosion Mechanisms Affecting Welded Marine Components in Seawater Environments

1. Uniform corrosion

Uniform corrosion occurs when metal loss is distributed relatively evenly across an exposed

surface. It is common in materials that lack sufficient protection in a given environment. For example, unprotected carbon steel can experience general corrosion in seawater. Although the process may be relatively predictable, continued material loss can reduce wall thickness and compromise structural integrity (Revie & Uhlig, 2008).

2. Pitting corrosion

Pitting corrosion is a localized form of attack that produces small cavities or pits. It is particularly important for stainless steel and other passive alloys exposed to chloride-containing environments. Pitting begins when the protective surface film breaks down at susceptible sites. Weld metal, heat-affected zones, surface contamination, and heat tint can influence pit initiation and propagation (Frankel, 1998; Davis, 2006). Welding-related changes in phase distribution, alloying-element concentration, and surface oxidation can cause the weld region to behave differently from the parent material. Research reviews on duplex stainless steel show that welding thermal cycles can influence phase balance and corrosion resistance, emphasizing the importance of process control (Mohammed et al., 2017; Verma & Taiwade, 2017).

3. Crevice corrosion

Crevice corrosion develops in confined spaces where the movement of seawater is restricted. Such spaces may occur beneath gaskets, deposits, fasteners, overlapping plates, and poorly designed joints. Differences in oxygen concentration between the crevice and surrounding surface can create localized electrochemical conditions that promote attack. Poor joint design and incomplete cleaning may increase the risk (Fontana, 1986; Davis, 2006).

4. Galvanic corrosion

Galvanic corrosion occurs when dissimilar metals are electrically connected in an electrolyte. The less noble metal generally corrodes preferentially, depending on the materials and environmental conditions. This mechanism is important in marine fabrication because stainless steel fasteners, aluminium panels, copper alloys, and carbon-steel structures may be connected in the same assembly. Suitable material combinations, electrical isolation,

coatings, and careful joint design can reduce the risk (Revie & Uhlig, 2008; Shifler, 2022).

5. Intergranular corrosion

Intergranular corrosion occurs preferentially along grain boundaries when local chemistry or microstructure makes these regions more susceptible to attack. In susceptible stainless steels, certain welding thermal cycles can promote chromium-carbide precipitation and chromium depletion near grain boundaries. The resulting loss of local corrosion resistance can compromise the joint, although the severity depends on the alloy grade, thermal history, and material condition (Lippold & Kotecki, 2005).

6. Stress corrosion cracking

Stress corrosion cracking results from the combined effects of a susceptible material, tensile stress, and a suitable corrosive environment. Weld residual stresses can contribute to the stress component, while seawater chloride can be particularly aggressive toward susceptible alloys. Appropriate material selection, control of welding procedures, stress management, and inspection are therefore important in critical marine equipment (Davis, 2006; Revie & Uhlig, 2008).

7. Microbiologically influenced corrosion

Microbiologically influenced corrosion (MIC) occurs when microorganisms and their biofilms change the chemical conditions at a metal surface. Biofilms may produce localized differences in oxygen concentration, pH, and chemical species, thereby encouraging corrosion in susceptible systems. Welded seawater piping, tanks, and other water-handling components may require appropriate cleaning, monitoring, and maintenance strategies (Davis, 2006).

Overall, the corrosion mechanisms discussed above show why visual inspection alone cannot establish the suitability of a welding technique. A weld may appear sound but still have poor resistance to pitting, crevice corrosion, or stress corrosion cracking. Consequently, corrosion testing should complement mechanical testing and weld inspection.

VI. INFLUENCE OF WELDING PARAMETERS ON CORROSION RESISTANCE

Welding parameters determine the thermal cycle, metal transfer, fusion, solidification, and cooling behaviour of a welded joint. These factors influence microstructure, chemical distribution, residual stresses, and surface condition. Consequently, inappropriate welding parameters can reduce corrosion resistance even when the selected base material has excellent resistance in its unwelded condition (Kou, 2003; Davis, 2006).

1. Welding current and voltage

Welding current and voltage influence arc energy, penetration, weld bead geometry, and the size of the heat-affected zone. Excessive energy may cause overheating and undesirable microstructural changes, while insufficient energy may produce incomplete fusion. Their effects depend on the process, material thickness, travel speed, and joint configuration (Kou, 2003).

2. Heat input and welding speed

Heat input represents the energy delivered per unit length of weld. Consistent units must be used, and the efficiency factor must be appropriate to the process. High heat input may increase the width of the heat-affected zone, grain growth, distortion, and the time available for unwanted precipitation. Conversely, excessively low heat input can produce rapid cooling and inadequate phase transformation in certain alloys. Duplex stainless steel therefore requires a controlled thermal window rather than simply the lowest possible heat input (Mohammed et al., 2017). Recent research on duplex stainless steel welds also demonstrates that welding current can affect the competing outcomes of pitting and intergranular corrosion resistance (Liu et al., 2024).

3. Filler-metal selection

Filler metal should be compatible with the base material and the intended service environment. Its chemical composition influences weld-metal strength, phase balance, solidification behaviour, and corrosion resistance. For example, suitable filler

metals for duplex stainless steel are selected to support the required ferritic-austenitic balance. An incompatible filler may produce a weld with inadequate mechanical or corrosion properties (Lippold & Kotecki, 2005; Verma & Taiwade, 2017).

4. Shielding gas and contamination control

Shielding gas protects the molten weld pool from atmospheric contamination. Inadequate shielding can cause oxidation, porosity, and changes in weld-metal chemistry. Surface contaminants, moisture, oils, and embedded particles can also contribute to defects or localized corrosion. Maintaining clean surfaces, suitable gas flow, and correct torch positioning is therefore essential (Kou, 2003; Davis, 2006).

5. Preheating, interpass temperature, and post-weld heat treatment

Preheating and interpass-temperature control influence cooling rate, residual stress, and microstructural development. Post-weld heat treatment may relieve some residual stresses or modify the microstructure, depending on the alloy and treatment.

However, inappropriate heat treatment can promote sensitization or harmful secondary phases. Treatment conditions must therefore be established for the particular material rather than applied universally (Kou, 2003; Lippold & Kotecki, 2005).

6. Welding procedure optimization

Welding procedure optimization should balance penetration, joint strength, corrosion resistance, productivity, and defect prevention.

This is particularly important for duplex stainless steel because its corrosion resistance depends partly on maintaining a suitable phase balance. For aluminium alloys, the focus may instead include controlling softening, distortion, and defects while preserving the required strength (Mohammed et al., 2017; Venugopal et al., 2023).

VII. MICROSTRUCTURAL CHANGES AND MECHANICAL PROPERTIES OF WELDED JOINTS

A welded joint is not metallurgically uniform. It generally contains the weld metal, fusion boundary, heat-affected zone (HAZ), and unaffected base material. These regions experience different temperatures and cooling histories, resulting in differences in grain size, phase composition, hardness, and residual stress (Kou, 2003). The weld metal forms through solidification of the molten material. Its microstructure depends on the base-metal and filler-metal composition, dilution, cooling rate, and solidification conditions. The HAZ does not melt completely but experiences temperatures sufficient to change its microstructure. Grain growth, precipitation, phase transformation, and local chemical changes can occur within this region (Lippold & Kotecki, 2005). In duplex stainless steel, the balance between ferrite and austenite is particularly important. Inadequate control of heating and cooling can leave an unfavourable phase balance or promote secondary phases, reducing toughness or corrosion resistance. This explains why welding procedures for duplex alloys require material-specific control of heat input, interpass temperature, and filler composition (Mohammed et al., 2017; Omiogbemi et al., 2021). The mechanical properties of welded joints are commonly evaluated using tensile, hardness, bend, and impact tests, where appropriate. Tensile testing measures the joint's ability to withstand pulling loads, while hardness testing helps identify local differences between the weld metal, HAZ, and base material. Bend testing assesses ductility and may reveal certain defects, whereas impact testing evaluates toughness under specified conditions.

These properties must be considered alongside corrosion behaviour. A weld may have high tensile strength but still exhibit poor pitting resistance. Similarly, a corrosion-resistant weld may be unsuitable if it contains cracks or fails to meet the structural requirements. Therefore, microstructural characterization, mechanical testing, and corrosion testing should be interpreted together rather than

treated as interchangeable measures of performance (Davis, 2006; Verma & Taiwade, 2017).

VIII. METHODS FOR EVALUATING THE CORROSION RESISTANCE OF WELDED MARINE COMPONENTS

The evaluation of corrosion resistance requires controlled testing that allows meaningful comparisons between welding techniques. The test programme should consider the base material, filler metal, weld region, surface finish, environmental conditions, and intended service requirements. Standardized procedures are valuable because corrosion results are sensitive to test preparation and exposure conditions (ASTM International, 2025a, 2025b).

1. Saltwater immersion testing

Immersion testing exposes specimens to a specified saline solution for a defined period. Specimens can be weighed before and after exposure, after suitable cleaning, to estimate mass loss and average corrosion rate. The test conditions should document solution composition, temperature, duration, solution volume, and specimen preparation (ASTM International, 2025a).

Immersion testing is useful for comparing general corrosion and observing corrosion products, but it may not accurately predict all forms of localized corrosion or long-term field performance. Results should therefore be combined with additional tests when pitting, crevice corrosion, or stress corrosion cracking is a major concern.

2. Salt spray testing

Salt spray testing exposes prepared specimens to a controlled saline mist. It is often used to assess coating performance and compare surface-treatment systems under defined conditions. However, salt spray results should not automatically be interpreted as a direct prediction of years of marine service because accelerated exposure may not reproduce the full range of natural seawater conditions.

3. Potentiodynamic polarization testing

Potentiodynamic polarization measures the electrochemical response of a material as its potential is varied. It can help estimate corrosion-related parameters and evaluate the susceptibility of certain alloys to localized corrosion. Cyclic polarization is especially useful for investigating pitting and repassivation behaviour in suitable iron-, nickel-, and cobalt-based alloys (ASTM International, 2024).

4. Electrochemical impedance spectroscopy

Electrochemical impedance spectroscopy (EIS) applies a small alternating electrical signal over a range of frequencies to characterize the electrochemical response of a metal-electrolyte system. When interpreted using an appropriate model, EIS can provide information about interfacial processes, passive-film behaviour, and protective coatings. Its results depend on test design and the validity of the selected model.

5. Pitting and crevice corrosion testing

Pitting and crevice corrosion testing is particularly important for stainless steel and other alloys used in chloride-rich environments. ASTM G48 describes methods for comparing the resistance of stainless steels and related alloys to localized corrosion in ferric chloride solutions. The results can be used to assess the influence of alloy composition, heat treatment, and surface finish (ASTM International, 2025b).

6. Metallography and microscopy

Metallographic examination involves preparing and examining a cross-section of the welded joint. Optical microscopy and, where appropriate, scanning electron microscopy can reveal grain structure, phase distribution, inclusions, cracks, and localized corrosion damage. These observations help explain why specimens produced by different welding techniques may exhibit different corrosion behaviour.

7. Integrated evaluation

A reliable evaluation should combine corrosion tests with mechanical tests and microstructural analysis. Corrosion rate, pitting behaviour, tensile strength,

hardness, defect frequency, and surface condition should be measured using consistent methods. Replicate specimens and suitable statistical analysis should be used to distinguish meaningful differences from experimental variability. For marine applications, laboratory results should ideally be supplemented by longer-term exposure or service data. No single accelerated corrosion test can fully represent all the mechanical, electrochemical, biological, and environmental conditions encountered in actual marine service.

IX. COMPARATIVE EVALUATION OF WELDING TECHNIQUES BASED ON CORROSION RESISTANCE, MECHANICAL STRENGTH, AND COST

Comparative evaluation is the central aspect of this review because it determines which welding technique is most appropriate for fabricating corrosion-resistant marine components. The comparison should consider corrosion resistance, mechanical strength, weld quality, productivity, equipment requirements, and lifecycle cost. The results must be interpreted in relation to the alloy and application rather than assuming that one process is universally superior (Messler, 2004; Davis, 2006).

1. Corrosion resistance

Corrosion resistance should be assessed by exposing welded specimens to controlled environments and measuring their response. For stainless steel and duplex stainless steel, useful indicators include corrosion current density, pitting potential, repassivation behaviour, critical pitting temperature, and observed pit density or depth. For carbon steel, mass loss and general corrosion rate may be particularly relevant, depending on the protection system and application (Frankel, 1998; ASTM International, 2025a, 2025b). GTAW can provide good corrosion performance when appropriate filler material, shielding, and surface preparation are used. GMAW can also produce corrosion-resistant joints when the welding parameters and consumables are correctly selected. However, poor shielding, excessive heat input, or unsuitable filler composition

can reduce the performance of either process. For duplex stainless steel, the balance of ferrite and austenite and the formation of undesirable phases are especially important (Mohammed et al., 2017; Verma & Taiwade, 2017). FSW is a useful comparison for aluminium alloys because it avoids bulk melting. However, its performance depends on the alloy, tool design, process parameters, and resulting microstructure. It should therefore be compared with fusion processes using equivalent materials, specimen geometries, surface preparation, and exposure conditions (Venugopal et al., 2023).

2. Mechanical strength and weld quality

Mechanical performance is commonly assessed using tensile strength, hardness, impact toughness, bend performance, and, where relevant, fatigue testing. The most suitable measures depend on the component's intended loading conditions. For example, cyclic loading of offshore structures may require fatigue assessment in addition to static tensile testing. Defects such as cracks, porosity, incomplete fusion, and excessive undercut can reduce structural reliability and create sites where corrosion may initiate. Weld inspection and acceptance criteria should be established in accordance with the applicable fabrication code and material requirements (International Organization for Standardization [ISO], 2023, 2025).

3. Productivity and economic considerations

The economic assessment should include equipment investment, consumables, labour, preparation, welding time, inspection, repairs, post-weld treatment, and expected maintenance. SMAW may be economically attractive for repair work because of its portability, while GMAW and SAW can be advantageous in repetitive, high-volume fabrication. GTAW may justify its slower production rate where precise control and weld cleanliness are critical. FSW may offer benefits for suitable aluminium structures, but tooling, clamping, and joint accessibility must be considered (Kou, 2003; Messler, 2004). Lifecycle cost is especially important for marine components because failure may result in downtime, repairs, environmental damage, and safety risks. A process with a higher initial cost may be preferable if it produces durable joints and reduces maintenance

requirements. Nevertheless, any claim of economic superiority should be supported by actual production and maintenance data.

Challenges, Research Gaps, and Future Perspectives in Marine Welding

Despite improvements in welding technology, the fabrication of corrosion-resistant marine components continues to face technical and economic challenges. These challenges arise from the interaction between material properties, welding thermal cycles, corrosive environments, and service loads.

Difficulty in maintaining corrosion resistance after welding

A major challenge is that welding can change the microstructure and surface chemistry of a material. In stainless steels, heat tint, local chromium depletion, and unfavourable phase changes may reduce resistance to localized corrosion. In duplex stainless steels, the balance between ferrite and austenite must be managed carefully. These issues make welding-procedure optimization and post-weld surface treatment important considerations (Davis, 2006; Mohammed et al., 2017).

Limited comparability between published studies

Published studies may use different alloy grades, filler metals, welding currents, heat inputs, surface treatments, exposure durations, and corrosion-test methods. Such differences make it difficult to determine whether a reported improvement is caused by the welding process itself or by other experimental factors. More standardized comparative studies are therefore needed.

Welding dissimilar materials

Marine structures may contain dissimilar metals for weight reduction, cost control, or functional reasons. Joining dissimilar materials introduces challenges related to thermal expansion, dilution, intermetallic-phase formation, galvanic effects, and differences in corrosion behaviour. Future work should investigate suitable transition materials, filler metals, joint designs, and protective measures for dissimilar-metal marine joints (Davis, 2006).

Limited long-term seawater performance data

Accelerated laboratory tests provide useful comparisons, but they do not fully reproduce long-term seawater exposure, marine biofilms, changing temperatures, flow conditions, fatigue loading, or combined corrosion and mechanical damage. Research should combine standardized laboratory tests with field exposure and service-performance data to improve the reliability of welding-process selection.

Advances in automated and hybrid welding

Robotic welding, adaptive process control, laser-hybrid welding, and advanced friction stir welding offer opportunities to improve consistency, reduce defects, and control thermal input. However, their benefits should be demonstrated using measurable outcomes, including corrosion performance, joint strength, defect rates, productivity, and lifecycle cost. Automation alone does not guarantee corrosion resistance.

Proposed research direction

A useful future study would compare GTAW, GMAW, and FSW for selected marine alloys, using only the processes suitable for each material. The study could evaluate corrosion rate, pitting resistance, tensile strength, hardness, microstructure, and fabrication cost under controlled conditions. For stainless steel or duplex stainless steel, GTAW and GMAW could be compared directly, while FSW could be evaluated separately for a suitable marine aluminium alloy.

The investigation should include replicate specimens, consistent surface preparation, clearly documented welding parameters, and recognized testing procedures. Statistical analysis would help determine whether observed differences are significant. Where possible, laboratory exposure should be supplemented by longer-term seawater testing.

IX. CONCLUSION

The evaluation of welding techniques for fabricating corrosion-resistant marine components requires an integrated understanding of materials, welding processes, corrosion mechanisms, microstructural

changes, and mechanical performance. GTAW, GMAW, SMAW, FCAW, and SAW offer different advantages for fusion welding, while FSW is an important option for suitable aluminium alloys. However, no technique can be considered universally superior without considering the material and service conditions. A reliable comparison should combine corrosion testing, mechanical characterization, weld inspection, productivity, and lifecycle cost. Particular attention should be paid to heat input, filler-metal selection, shielding, surface preparation, and post-weld treatment. Future research should prioritize standardized comparisons and long-term marine exposure data to improve the reliability and durability of welded marine components.

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