RESEARCH ARTICLE OPEN ACCESS

Review On Under Water Welding

Aryan Rajput [a], Aum Soni [a] , Nayan Harsiyani [a] , Sudhanshu Thakur [a]
Mr. Vivek Parikh [b], Mr. Chinten Morsiya [b]
[a] *Student of Mechanical Engineering, L.J University, Ahmedabad, India*
[b] *Professor, Mechanical engineering Department, L.J University, Ahmedabad, India*

ABSTRACT
Underwater welding is an essential technology widely used in naval construction, offshore infrastructure maintenance, and the repair of submerged structures such as ships and pipelines. It is primarily classified into wet welding, dry welding, and hybrid welding techniques. Wet welding, using shielded metal arc welding, is the most commonly applied method for structural steel repairs in shallow waters. However, it faces challenges such as arc instability, weld porosity, hydrogen embrittlement, and rapid cooling, which can affect the weld's strength and durability.

To address these challenges, various advancements have been introduced. Adhesive-assisted submerged arc welding effectively reduces water interference, leading to high-performance, defect-free welds. The development of flux-cored arc welding has significantly improved microstructural optimization and porosity control, enhancing the overall weld quality. Hybrid welding, combining laser radiation with electric arcs, has been explored to stabilize the welding process and produce uniform weld seam.

Underwater welding robots play a crucial role in overcoming challenges related to efficiency, performance, and safety in underwater welding operations. These robots must address both hardware deployment and software algorithm complexities. The integration of humanoid robots and artificial intelligence (AI) has emerged as a promising solution to enhance underwater welding capabilities.

Future developments in underwater humanoid welding robots (UHWR) focus on both underwater apparatus and terrestrial support systems. AI plays a key role in optimizing various aspects of UHWR, including multi-sensor calibration, vision-based 3D reconstruction, weld feature extraction, decision-making for weld repairs, and robot trajectory planning.

Date of Submission: 11-03-2025 Date of acceptance: 24-03-2025

I. INTRODUCTION

Underwater welding is classified into wet welding, dry welding, and local dry welding. Wet welding (UWW) is the most widely used due to its simplicity, cost-effectiveness, and flexibility, making it essential for emergency repairs on submerged structures. In contrast, dry welding, performed in gas-filled chambers, offers higher weld quality but is costly and complex.

Despite its advantages, UWW faces challenges such as rapid cooling, hydrogen embrittlement, porosity, and arc instability due to direct water exposure. Studies indicate significantly higher diffusible hydrogen levels in UWW welds compared to land-based welding, increasing the risk of cracking and mechanical degradation.

Since its early 20th-century development, UWW has evolved significantly. While traditional Shielded Metal Arc Welding (SMAW) remains common, alternatives like Gas Metal Arc Welding (GMAW) offer continuous welding but struggle with arc instability. Recent advancements focus on self-protecting flux-cored arc welding (FCAW), which minimizes hydrogen ingress and improves weld integrity.

Modern research emphasizes consumable optimization, automation, and hybrid welding techniques to enhance UWW's efficiency and applicability in deeper, more complex underwater environments. This paper reviews these advancements, bridging historical challenges with innovative solutions for improved underwater welding performance.

II. ENHANCEMENT TECHNIQUES FOR THE IMPROVEMENT OF UNDERWATER WELDING

Underwater welding is primarily categorized into dry and wet welding methods. Dry welding involves creating a gas-filled chamber around the weld site, ensuring better weld quality. In contrast, wet welding is performed directly in water using waterproof electrodes, making it more cost-effective but prone to defects due to rapid cooling and arc instability.

Several challenges impact the effectiveness of underwater welding, including arc bubble formation, reduced arc stability, and the presence of halogens that affect weld strength. Studies have shown that increasing the stability of the arc and controlling bubble dynamics can significantly improve weld quality. Techniques such as ultrasonic-assisted welding, local cavity methods, and the use of specialized coatings have been explored to enhance weld performance. Additionally, optimizing welding parameters such as current, arc length, and shielding gases has shown promising results in improving mechanical properties.

Recent advancements have focused on refining welding electrodes, incorporating elements like titanium and boron to promote finer microstructures and reduce porosity. Researchers have also investigated the role of shielding gases and mechanized welding processes to ensure greater consistency and safety for divers.[2]

compared to traditional underwater wet welding (UWW), the USAW process significantly improves weld quality and stability. The cooling rate in USAW was reduced by 54.51%, leading to finer microstructures and defect-free welds. The resulting welded joints exhibited higher mechanical properties, including an increase in tensile strength from 407 MPa to 463 MPa and an improved bending angle from 62.5° to 180°. Additionally, the USAW method enhanced impact toughness, maintaining a toughness value of 63 J/cm² at 0°C, far superior to conventional UWW.[3]

III. DRY UNDERWATER WELDING BASED ON MICRO DRAIN COVER

Traditional methods like wet welding or bulky dry chambers often compromise efficiency and weld quality. The newly designed micro drain cover employs a dual air curtain structure to isolate the arc from water, creating a stable gas environment. Experiments were conducted on AISI 304 stainless steel at 40 cm depth using 14 parameter sets, varying currents, gas pressures, and welding speeds.

Key results identified Parameter Set No. 09 (70–72 A base/median current, 310 A peak current, 0.3 MPa shielding/drainage gas) as optimal, yielding uniform weld width, minimal defects, and no porosity. Microstructure analysis revealed an austenite matrix with δ-ferrite at grain boundaries, enhancing corrosion resistance while maintaining ductility. Mechanical tests showed an average yield strength of 594.5 MPa and ductile fracture patterns in the heat-affected zone (HAZ), with microhardness averaging 210 HV in the weld.

The micro drain cover effectively stabilized the arc, achieving weld quality comparable to land-based processes. This innovation holds promise for automated, high-efficiency underwater repairs in radiation-sensitive environments like nuclear spent fuel pools.[7]

IV. UNDERWATER LASER WELDING

laser-stabilized flux-cored arc welding for underwater applications, aiming to improve arc stability and weld quality compared to traditional methods like manual electrode welding. By combining a low-power NIR laser (1030 nm wavelength, 0.7–2.8×10^4 W/cm² power density) with an electric arc, the researchers tested parameters such as laser power, arc current, arc force, and geometric alignments on steel samples (S235-JR).

Arc stability significantly improves with higher arc force (100%) and additional laser energy input, reducing power deviation by up to 46%.

Laser radiation increases arc voltage by altering arc resistance, enhancing weld seam homogeneity and reducing porosity.

A minimal overlap (≤2 mm) between the defocused laser spot and arc is sufficient for stabilization, demonstrating robustness against positional offsets.

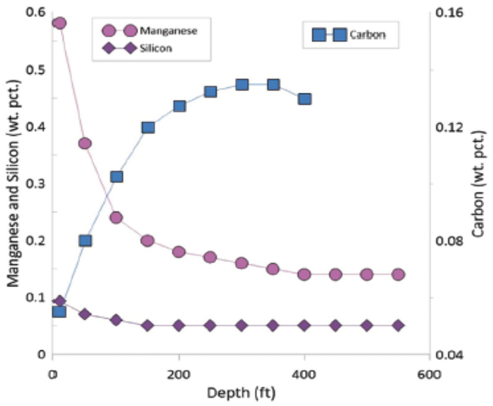
Rapid underwater cooling challenges were mitigated, yielding consistent weld geometry and microstructure. The method shows promise for industrial underwater welding, offering stable, continuous operation with reduced costs compared to high-power hybrid systems. Future work may focus on optimizing parameter interactions and scaling the process for deeper underwater applications[6]

local dry underwater laser welding for pure titanium (cp-Ti) using air as an assisting gas, aiming to provide a cost-effective method for in situ repairs of underwater structures. Traditional underwater welding often relies on inert gases like argon, which are expensive and logistically challenging. The researchers employed a fiber laser setup in a simulated underwater environment, testing various welding speeds (1.0–3.0 m/min) and comparing results to atmospheric welding.

Key findings revealed that underwater welds exhibited a three-layer structure: an oxide layer, oxygen-enriched zone, and oxidation-free core. Oxidation was driven by high-temperature water vapor and gas turbulence from the air-assisted local dry method, with porosity defects exacerbating oxygen diffusion. Despite surface oxidation, underwater welds maintained complete penetration and minimal surface defects, comparable to atmospheric welds in cross-sectional geometry[4].

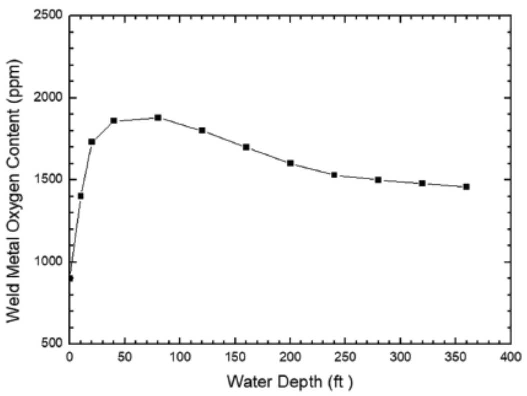
V. CHEMICAL COMPOSITION FOR OPTIMIZING WELD MICROSTRUCTURE AND DEFECTS IN UNDER WATER WELDING

Alloying elements (e.g., Mn, Si) diminish with water depth, degrading weld toughness. Recent innovations involve adding Ti and B to flux coatings, promoting acicular ferrite formation, which enhances toughness and refines microstructure. Polymer-based binders in electrodes reduce moisture absorption, further improving weld integrity



(Fig.1— Underwater wet weld metal manganese and silicon contents as a function of water depth)

manganese contents reduced by as much as 250% going from the surface to a 300-ft (91.4-m) water depth. Silicon experienced a 50% loss in the same depth range - Fig. 1. After a certain water depth, (e.g., 200ft), the weld deposit was described as essentially iron with very small amounts of manganese and silicon. With such large changes in manganese and silicon content, the weld metal microstructure and mechanical properties were expected to change accordingly.



(Fig. 2 — Underwater wet weld metal oxygen as a function of depth)

In underwater wet welds, there are three principal kinds of discontinuities —

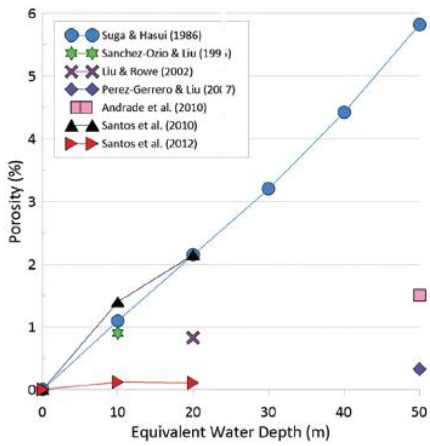
1)pores :- refer to small voids or cavities that form within the weld due to trapped gases.

2)cracks:- fractures or separations in the weld metal or the base material.

3)inclusions:- the presence of foreign materials or impurities within the weld, Common types of inclusions include slag, oxides, and other contaminants.

They occur in a wide range of sizes (from nm to tens of microns), shapes (elongated, platelet, and spherical). With increasing water pressure, the oxygen content in the weld metal tends to reach its solubility limit and react with deoxidizer elements in steel (Fig. 2), leading to the formation of spherical oxide inclusions . Synchrotron tomography and focused ion beam scanning electron microscopy(FIB-SEM) can be used in the characterization of inclusions.

Studies developed in previous decades concluded that CO formation and H diffusion to the pores, and are responsible for pore growth in underwater wet weld metal

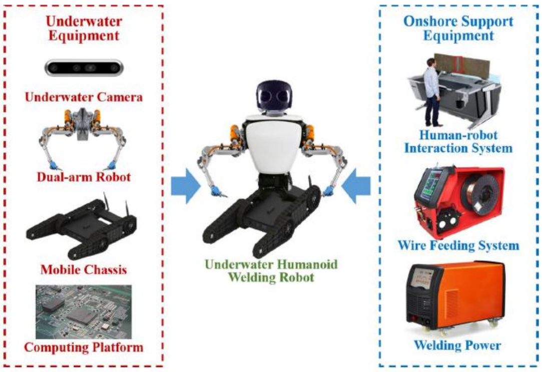


(Fig.3Effect of pressure on the weld metal porosity)

Pore formation is minimized through optimized slag systems (e.g., TiO_2-SiO_2-CaO) and additives like calcium carbonate. These reduce hydrogen solubility and stabilize gas reactions.[5]

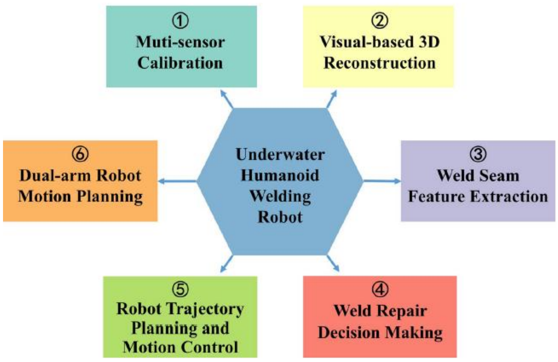
VI. ARTIFICIAL INTELLIGENCE AND UNDERWATER WELDING ROBOTS

Underwater welding robots (UWRs) are crucial for improving efficiency and safety in underwater construction and repair. Traditionally, UWRs consist of Remotely Operated Vehicles (ROVs) and Autonomous Underwater Vehicles (AUVs), with ROVs relying on tethered control and AUVs operating independently. However, challenges such as power constraints, posture estimation, and fluid dynamics fluctuations hinder welding precision.



(Fig.4 hardware of underwater humanoid welding robots (UHWR))

Recent advancements in artificial intelligence (AI) and humanoid robotics offer promising solutions. AI enhances multi-sensor calibration, 3D reconstruction, weld feature extraction, and trajectory planning, improving welding accuracy and adaptability. Humanoid welding robots (UHWRs) are being developed with dual-arm robotic systems, underwater cameras, and computing platforms to mimic human dexterity in hazardous underwater environments.
Despite these advancements, challenges remain in optimizing AI algorithms for real-time decision-making, improving hardware durability, and addressing environmental complexities like water ingress and visibility. Future research focuses on integrating edge computing, developing multifunctional AI models, and enhancing real-time control systems to advance UHWR capabilities for deep-sea and industrial applications.[1,8]



(Fig.5 software of underwater humanoid welding robots (UHWR))

VII. CONCLUSION

Underwater welding continues to evolve as a critical technology for marine infrastructure maintenance, driven by innovations in process design and automation. Traditional challenges, such as rapid cooling, water interference, and weld defects like porosity, cracking, and oxidation, are being systematically addressed through advanced methodologies. Techniques such as organic adhesive-assisted submerged-arc welding and local dry environments (e.g., micro drain covers or gas-assisted systems) effectively isolate the welding zone, stabilizing arc conditions and reducing defects. These approaches promote refined microstructures and enhanced mechanical properties, improving weld integrity and resistance to environmental stressors like corrosion and thermal shock.

The integration of artificial intelligence (AI) and robotics marks a transformative shift in underwater welding. AI-driven systems enhance process control through real-time monitoring of parameters like arc stability, thermal cycles, and defect detection, enabling adaptive adjustments to mitigate flaws. Robotics, particularly humanoid and dual-arm systems, introduce precision and flexibility, performing complex tasks such as seam tracking, trajectory planning, and multi-pass welding in constrained underwater environments. AI algorithms further optimize decision-making for weld repair strategies, leveraging from vision-based 3D reconstruction and multi sensor feedback to predict and correct anomalies.

REFERENCES

[1]. Hui Gao, Xiangdong Jiao, Chanfeng Zhou, Qiuping Shen, Yan Yu. Study on Remote Control Underwater Welding Technology Applied in Nuclear Power Station. Elsevier-2011
[2]. S. Godwin Barnabas , S. Rajakarunakaran , G. Satish Pandian , A. Muhamed Ismail Buhari,V. Muralidharan. Review on enhancement techniques necessary for the improvement of underwater welding. ELSEVIER-2020
[3]. Shengfa Dong, Yanfei Han, Chuanbao Jia, Chuansong Wu, Maofu Zhang, Qingyuan Yang ,Jie Yang. Organic adhesive assisted underwater submerged-arc welding. ELSEVIESR-2020
[4]. Manlelan Luo, Pengyu Wei, Quanhong Li, Renzhi Hu, Anguo Huang and Shengyong Pang. Underwater Laser Welding of Pure Ti: Oxidation and Hardening. MDPI-2021
[5]. E. C. P. PESSOA AND S. LIU, The State of the Art of Underwater Wet WeldingPractice. Welding Journal-2021.
[6]. Marcel Riecka , Jens Koglin , Benjamin Emde, Jörg Hermsdorf. Influence of NIR-laser radiation on the underwater arc welding process with flux-cored wire. ELSEVIER-2024.
[7]. Leigang Hana, Xiangmiao Wub, Guodong Chenc, Zhenmin Wanga, Wenyan Fan. Local dry underwater welding of 304 stainless steel based on a micro drain cover. ELSEVIER-2024

[8]. Peng Chi , Zhenmin Wang, Haipeng Liao,Ting Li, Xiangmiao Wu & Qin Zhang Application of artificial intelligence in the new generation of underwater humanoid welding robots. RESEARCH GATE-2024