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Review Article

Review of Underwater Friction Stir Welding: Analysis of Joint Mechanical and Microstructure, Properties and Process Modeling

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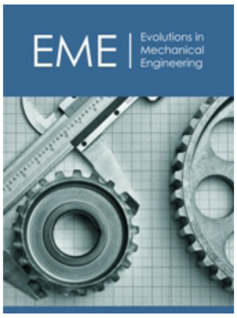

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Abstract

Underwater Friction Stir Welding (UWFSW) is a valuable adaptation of conventional Friction Stir Welding (FSW) with the potential to supplant fusion welding methods. UWFSW has been widely reported and utilized in several industrial applications. The study compiled information from available sources on the process features, variations, macro-and microstructural characteristics, mechanical properties of the resulting joints, and numerical simulations of the UWFSW process. Furthermore, the study also examined the utilization of UWFSW in the aerospace, aviation and automobile sectors. The current challenges and issues of UWFSW were identified.

Keywords: UWFSW; Welding in solid state; Qualities of welding; Quality of welding

Introduction

Aluminum alloys, lightweight metals, are frequently employed in aerospace and automotive industries due to the critical need for weight reduction [1]. FSW is gaining increased interest in industrial applications and research as a solid-state welding method [2]. The need for supply in many applications of FSW is rising among engineers, producers, and the market, prompting researchers and analysts to respond. Experimental research is both time-consuming and expensive. Simulation and modeling methods will provide a more thorough, cost-effective, and efficient understanding of the process in this scenario, which has been recently introduced as a novel solid-state welding method. The process occurs at temperatures below the material's melting point when the rotating tool's shoulder scrapes on the alloy surface of workpieces while submerged in water. The tool pin generates sufficient heat through friction to melt the workpiece, facilitating the swirling of the melted material and inducing plastic deformation to create a weld connection [3,4].

Review of Literature

Heirani F et al. [5] employed the "slipping and sticking" technique with 1100-H14. They analyzed torque oscillations that occur at the same frequency as the tool rotation because of the cyclic material transfer in butt welds. Their analysis did not encompass oscillations of lower frequencies. Liu W et al. [6] concentrated their research on the issue of keyhole formation near the end of the welded workpiece, leading to material wastage. Hewidy AM et al. [7] determined that the paper discusses the UWFSW of stir-cast aluminum-based alloy (Al 6061) by varying weight percentages of silicon carbide (5%, 10% and 18%). He confirmed this by carrying out validation experiments. The current investigation found that the UTS is 984MPa, and the microhardness is 89.9HV, which aligns with previous effectiveness investigations. Gad Allah N et al. [8] The paper discusses the UWFSW of Al 6063 alloy using three levels for process parameters. The current investigation found that Al 6063 pipe can be welded utilizing the UWFSW process by a maximum welding competence of 92.7%. Sabry et al. [9]. The research examines the viability of using FSW and UFSW to join Al 6061/5, Al 6061/10 and Al 6061/18wt. %SiC composites generated using the reinforced stir casting technique. Two rotating rates, 1000 and 1800rpm and speed of traverse 10mm per minute were analyzed. Composite plates, each 10mm thick, were effectively welded using FSW. The study found that the UTS of the welded connection using FSW and UFSW at a rotation speed of 1800rpm for (Al 6061/18 wt. %SiC composites) was 195MPa and 230MPa, respectively. The UTS of the welded joint using FSW and UFSW on Al 6061/18 wt.% SiC composites were 165MPa and 180MPa, respectively. Thekkuden DT et al. [10] The research aims to explore the potential of UWFSW for creating high-quality welded pipe joints. The research first concentrated on creating a system with appropriate components and fixtures connected to the vertical milling machine for UWFSW of pipes. UTS is determined through experimental analysis of tensile tests. The predictive performance of machine learning methods such as ANN, ANFIS, and adaptive neuro-fuzzy inference system with Harris optimization (ANFIS-HHO).

El-Zathry NE et al. [11] this study examines the UTS of Al 6063-T6 material utilizing UWFSW with Three parameters that were altered throughout the creation of test specimens. Utilizing ANN-GA and ANFIS-GA. The outcomes of this study hybrid models created can be utilized to forecast and optimize particular process parameters and effects across various industrial scenarios. Nader Zaafarani et al. [12] This study analyzed the differences in parameters between FSW and UWFSW on the weld joint, including tool rotation speed, transverse speed and wall thickness. The UTS of the weld joint was compared through experimental work conducted on FSW and UWFSW using a newly modified fixture to address post-process issues. The study found that using UWFSW results in higher UTS than regular FSW. Abdel-Mottaleb M et al. [13]. This study discusses the creation of a fuzzy model to predict weld quality, and the main criteria that significantly impact the quality of UWFSW are process parameters. Weld quality is assessed based on UTS and VH utilizing fuzzy logic and the outcomes are contrasted with statistical analysis. Confirmatory experimental findings demonstrate that the fuzzy model can forecast output more accurately than statistical analysis. Ahmed M El-Kassas et al. [14] designed new equipment to implement UFSW on Al 1050 pipes effectively. A study was conducted to determine and forecast the UWFSW process parameters' impact on the mechanical qualities of the welded joint. A hybrid model combining Response Surface Methodology and Fuzzy logic was developed and assessed to anticipate the desired outcome of the UWFSW process. This model demonstrated superior predictive accuracy compared to the Artificial Neural Network model.

Abdel-Hamid Ismail Moura et al. [15] this research examines the application of UWFSW and traditional FSW on AL 6063 pipe junctions using specially designed equipment. The fixtures are created and constructed to support the two pipes securely. Welding settings are determined through a series of trials to achieve high-quality welding. The immaculate welds demonstrate the effectiveness of the underwater friction stir procedure for welding pipes. Submerged FSW is an enhanced version of FSW that is conducted in a medium like water or brine. Based on prior studies, the authors of [16] have thoroughly examined the benefits and drawbacks of submerged FSW compared to FSW conducted in the air. Aluminum alloy materials are extensively utilized in maritime and shipbuilding industries because of their exceptional corrosion-resistant qualities. Multiple studies have investigated the UWFSW of lightweight materials such as aluminum alloy [17], aluminum pipe [18] and magnesium alloy [19]. In addition, welding other materials like aluminum alloy and magnesium alloy [20], aluminum and steel [21], aluminum and stainless steel [22], and composite materials have been studied in underwater environments previously [23]. Raising the speed of rotational tool and decrease the welding speed in UWFSW has a notable positive impact on the mechanical qualities of the joints, similar to conventional FSW [24]. Majumder S et al. [25] discovered that the sequence in which the process factors impact the hardness of underwater welded joints was rotating speed, traverse speed, and pin length. Microcracks and porosity were detected through dye penetrant testing in the UWFSW joints created at minimum speeds but not at maximum speeds. Grain refinement is crucial in UWFSW due to the rapid cooling rate and reduced peak temperature, resulting in enhanced UTS and VH [26,27]. The heat generated causes dynamic recrystallization, forming fine equiaxed grains that enhance the mechanical characteristics of the welded joints. In traditional FSW, voids are present. In UWFSW, also known as submerged FSW, the void size and fractional void area decrease, which helps to postpone fracture caused by cavities [28].

Khalaf et al. [29] found that the FSW of aluminum alloy produces greater heat than the UFSW in both experimental and computational studies. FSW produces greater heat, which leads to increased material softening compared to UFSW. Increased cooling rate and regulated heat output in underwater settings decreased residual stress and strain. The authors studied the FSW of 1 mm thick titanium in air and water and analyzed the tensile properties of the joints created under various process settings [30]. The yield strength and tensile strength of the SFSWed joints are significantly greater than those of the FSW joints. The enhanced tensile qualities of SFSW result from effective stirring for complete mixing and the strengthening impact of the aqueous environment. Warpage occurred following welding in both FSW and Self-Reacting FSW due to the 1mm thickness of the sheet material. The primary constraints of the SFSW process are the increased torque and power consumption.

Uses, benefits and restrictions of UFSW

The main uses of the UWFSW method include constructing large ships that exceed the capabilities of current harbors, ship maintenance and repairs, emergency ship reconstruction, retrieving sunken containers and offshore pipeline construction. The benefits of the UWFSW method include high-quality and strong joints produced quickly, no need for filler metals or shielding gases, compatibility with various metals, ease of operation, and flexibility in all positions due to simple automation. Additionally, the UFSW method can weld various incompatible materials, create fine-grained forged joints by eliminating weld inclusions or dilution, and make reliable welds using less energy in the joining process. UFSW poses challenges in inspecting welded connections compared to standard FSW, making it more difficult to ensure high-quality joints and increasing the possibility of inadequate fault detection. Additionally, it necessitates costly machinery and machine tools [31].

Potential future of UFSW

Prior extensive research has been conducted to enhance the underwater FSW method's control techniques and process performance. However, numerous conflicts need to be resolved and the UWFSW exploration should concentrate on extensively studying the characteristics of welded material and process optimization. Research on UWFSW should focus on utilizing robot manipulators for underwater FSW joints with complicated geometry to enhance the automation of joining and inspection processes. Additionally, efforts should be made to expand the applicability of UWFSW to big and complex structures [32]. This technique should focus on thermal management, including closed-loop temperature control and thermal boundary condition modification. It should also aim to enhance in-process weld quality assurance, expand the use of UWFSW to various engineering materials, and improve control techniques for continuous welding.

Literature Review Gaps

Based on the literature review, it is evident that minimal research has been conducted on underwater FSW. It is a highly sophisticated welding method. The optimization approach has been underutilized in friction stir welding research, especially in UFSW. UFSW remains unexplored.

Synopsis and Viewpoints

UWFSW is an advanced and sophisticated joining technology in the current era. The literature study reveals few studies conducted on the UWFSW process. UWFSW is recognized as a sophisticated welding method, and only a few studies have utilized optimization techniques in this sector. UWFSW has not been thoroughly investigated yet. By directing future research toward it, we may improve and achieve high-quality weld joints under cost-effective, environmentally friendly, and safe welding conditions.

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