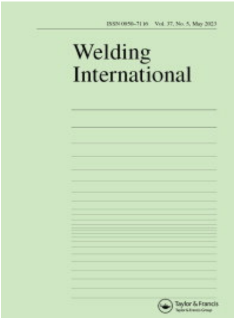


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RESEARCH ARTICLE



# An evaluation of mechanical properties and estimation of environmental reduction factors in welded API X70 steel pipeline in natural seawater

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**ABSTRACT**

Due to the detrimental effect of damage induced by seawater in pipeline structures, there is a need to investigate the effects of natural seawater and air environments on mechanical properties of representative pipeline materials, to obtain useful data for estimation of their service lives. Hence, in this work, a X70 steel pipeline plate was welded using submerged arc welding technique; and subjected to air and natural seawater environments. Test specimens were soaked in seawater for twelve months at 28 °C. The parent plates, weld regions and the heat affected zones were investigated by evaluating their mechanical properties and fracture surfaces. The experimental findings revealed that the tensile strengths of parent and weld were 634.00 MPa and 674.00 MPa respectively, while the compressive stresses were 750.10 MPa and 750.40 MPa respectively with highest hardness value of 239HV. The findings also revealed that weld area and heat affected zone depend on material thickness, heat input and possible effect of residual stresses in the weldment. The fracture surfaces of test specimens showed combination of brittle and ductile failure mechanisms. Comparison of the test results revealed that seawater had significant effect on the mechanical properties and surface morphology of the API X70 steel pipeline with respect to immersion time.

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**KEYWORDS**
Welding; pipeline; mechanical properties; fracture; air; seawater

## 1. Introduction

Welding is an economical method for joining metals and is one of the most commonly used techniques for fabricating various welded structural components [1–4]. Welding has made significant impacts on the numerous pipelines and petrochemical industries by improving the operational efficiency, productivity and service lives of their plants and relevant equipment [5, 6]. Also, pipelines are classified according to their strength, chemical composition and application areas and they are supplied in a variety of thicknesses each of which is specific to the area of application [7]. Despite the fluctuations in oil prices globally, oil and gas pipelines are still used considerably and remains the only transportation medium for oil and gas products [8]. However, owing to the increasing demand for steel globally, steel manufacturers are currently using advanced manufacturing techniques to reduce weight and costs while improving mechanical properties by using innovative technology to improve pipeline products as well as welding processes that drive innovation. Moreover, pipelines are generally prone to failure because of the types of loads they carry and the nature of the environmental-induced damages they sustain during operation [9]. Aliu [10] mentioned that these pipelines are sections made from different grades of steels such as X70, X80 and X100 steels. However, according to the American Petroleum Institute (API), pipelines are classified as API X42, X52, X65, X 70, X80, X100 and X120 [11]. It has been reported that the addition of alloying elements such as C, Si and Mn to steels could enhance their strength by the formation of martensite and bainite [12]. Hence, pipeline steel grades are selected according to specific area of application and the environment. For example, API X70 steels are mostly used in the shipping industry, in oil storage tanks and for temporary bridges during road construction, in addition to being used for transportation of oil

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and gas products [13]. However, the X70 steel grade is the highest pipeline steel grade that can be manufactured with a pearlite-ferrite microstructure without compromising weldability [14]. X70 contains a ferrite–pearlite matrix, as demonstrated by the variation in the microstructure in some API steel grades. Specifically, Aliu [10] demonstrated that the failure mechanisms of X70 steels particularly in the welded sections have not been adequately investigated. These mechanisms include tensile, impact, compression and hardness properties with respect to the effect of operating environment on the steel sections. Additionally, the failure mechanisms and the environmental influence on the structures are site-dependent; therefore, operators and design engineers must consider and understand the degree of damage that could be caused by the environments in order to ensure that the structures satisfy their design requirements.

Welding is the most widely used method for fabricating pipelines because pipelines usually cover long distances [15]. This fabrication technique can be performed with or without the use of filler materials. Continuous welding performed without filler materials while electric welding and laser welding which includes submerged-arc welding (SAW) and gas metal-arc welding [16]. However, the SAW process has proven to be useful for fabricating longitudinal and circumferential butt-weld joints in pipelines and pressure vessels. SAW is preferred over other methods of welding steel pipeline plate because of its high reliability, deep penetration, smooth finishing and high productivity [17]. This welding process has also gained attention for the fabrication of pressure vessels, marine vessels, pipelines and offshore structures and because of its high deposition rate, excellent surface appearance, invisible arc and minimal welder skill requirement. It is an attractive welding process for large pipes, large vessels components with heavy wall thicknesses [18]. Figure 1 depicts the SAW process. A continuous solid bare electrode and a blanket of powdered flux are used in SAW. The flux mount is sufficiently deep to submerge completely the arc column so that there is no spatter or smoke and the weld is shielded from the atmospheric gases. Flux physically influences the weld zone as it affects weld bead geometry and load carrying capability [19]. It also affects the chemistry of the weld metal by altering the mechanical properties [20,21] and microstructure [22]. The heat produced by the arc is used to melt the work piece. Hence, the SAW process produces a high-quality weld with the desired composition without the use of pressure [23]. Though, some researchers have utilised unconventional techniques, such as solid state for welding of pipes. Maggiolini et al. [24] studied crack path and defects under various loading conditions (torsion, tension and biaxial tension–torsion loading) when developing new friction stir welding process for joining small diameter tubes. The authors revealed that in terms of fatigue design, loading conditions do not affect the location of crack initiation in any significant way. However, small variations were observed in the fatigue test at stress ratios of 0.1. Also, Salvati et al. [25] conducted a microstructural investigation of a 4 mm thick AA6082-T6 HYB butt-weld with interest in the weld region and the thermo-mechanical affected base material. The research findings revealed the formation of sharp interfaces or porosity between the base and the filler material. In addition, Tognan et al. [26] investigated and compared the residual stresses in two solid-state welding processes (friction stir welding as well as hybrid metal and extrusion bonding) using 4 mm thick AA6082-T6 butt welds. The authors found that hybrid metal and extrusion bonding joints yielded higher magnitude of tensile residual stresses compared to in friction stir weld joints. However, the results were attributed to the lower yield stress point exhibited by the filler materials.

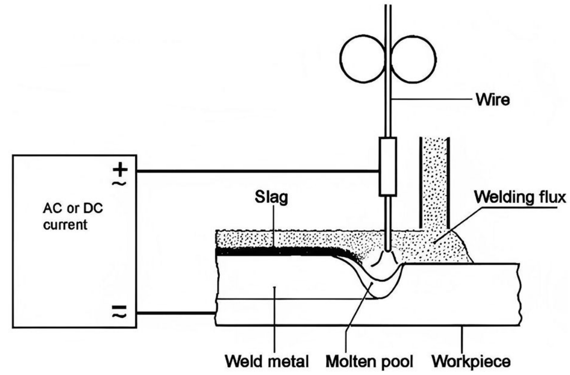


Figure 1. Submerged-arc welding (SAW) process [19].

Tusek and Suban [27] revealed that welding arc efficiency and metal deposition rate could be increased by employing metal powder. Thus, Ghosh et al. [20] studied the effect of increasing