A Review on Effects of Weld Process Parameter on Weldability and Corrosion Behavior of Duplex Stainless Steels

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Abstract

An attempt has been made in this study to examine the metallurgical, weldability, and corrosion aspects of industrial marine alloy duplex stainless steel. The effects of different fusion and solid-state welding processes on joining with related and dissimilar metals are discussed. It is designed for an application that requires a very high amount of strength and corrosion resistance. The high chromium, nickel, and molybdenum provide good resistance to pitting, crevice, and general corrosion. Being Austenitic stainless steel, it has some qualities such as corrosion resistance, high strength, and high concentrations of chromium and nickel. However, it will emphasize material growth, microstructure, corrosion properties such as critical pitting corrosion temperature and crevice corrosion resistance, duplex stainless steel heterogeneous deformation behavior, and mechanical properties such as tensile properties, fatigue properties, and hardness.

Keywords: Duplex Stainless Steel, Joining processes, Welding, Corrosion Behavior

1. Introduction

The astounding popularity of duplex stainless steels (DSSs) over austenitic stainless steels (ASSs) is due to demand nickel (Ni) price fluctuations year on year [1]. Another problem with stainless steel is that they have a shorter lifespan in certain hostile situations [2]. As a result, companies are looking for substitutes with low Ni content and similar performance to traditional stainless steel [3]. They have a two-phase microstructure made up of ferrite and austenite and are often graded based on their pitting resistance counterpart. Duplex stainless steels have promising performance in many corrosive conditions, with superior localized corrosion resistance due to a half ferrite and half austenite percentage [4,5]. The duplex stainless steel is widely known for its high strength; excellent corrosion resistance and they are also easy to fabricate. Duplex stainless steel (DSS) is widely used in the marine, chemical industries, paper and pulp industries, petrochemical, and offshore industries due to its superior mechanical properties and high corrosion resistance [6,7]. The PRE is an empirical way of defining a DSS's corrosion resistance based on the sum of elements adding to the corrosion resistance. PRE can be calculated in a variety of ways, but the most common is to use a formula that includes the contents of chromium, molybdenum, and nitrogen (PREN55Cr 3.3 Mo 16 N) [8-10]

Duplex steel possesses excellent resistance to hot cracking so major problems occur within the Heat Affected Zone (HAZ) only, but some common challenges which can be faced during welding of duplex steel are not getting the heat input and inter pass temperatures right, there are adverse effects of heat on duplex steel as low heat input or high inter pass temperature can disrupt the delicate balance of austenite and ferrite, and it also affects toughness and corrosion resistance of duplex steel constant check and balancing of heat input and inter pass temperatures must be carried out while the welding of duplex steel and without proper impact toughness, corrosion resistance and ferrite/austenite mix test, it is impossible to deliver a reliable weld [11]. Aside from that, the scientifically useful study is presented at several conferences, which has increased the enormous market for DSSs around the globe. Since 1982, these conferences have been held regularly. These conferences included an outstanding mix of insightful research contributions and technical lectures, as well as metallurgical aspects. Among the stainless-steel types, the global production of DSSs is less than 200 kT, or around 1% of the total global production of SSs, despite consumption being close to 100%. DSS demand was 0.6 percent in 2004 and increased to 1 percent in 2007, according to the International Stainless-Steel Forum (ISSF) [12]. It was predicted at the Feinox 2008 conference that DSS demand would rise by 4% for the year 2020, the output is expected to increase by 53% by 2020. ASSs production was 53.4 percent in 2013, and 54.6 percent in 2014 [13]. Many considerations affect the properties of dissimilar welding joints and also the viability of welding techniques, such as carbon migration from the low alloy side, microstructure gradient, and varying residual stress conditions through various regions of weld metal [14]. Due to many demanding situations in industrial projects mainly economic benefits and the advantage of outstanding performance of two different metals, necessitate dissimilar welding of metals by fusion welding methods [15]. TIG welding is one of the most commonly used welding processes in the stainless-steel industry for high-quality welds and low investment in nonferrous metals and alloys such as Al, Mg, and Ni-related alloys [16]. The weld bead geometry is an essential aspect of TIG welding. The weld bead geometry is critical in determining the mechanical properties of the well [17]. It is very challenging because of differences in the physical, mechanical, and metallurgical properties. The selection of proper filler material is one of the major challenges because, on one hand, it must help in the prevention of weld metal (WM), liquation cracking, heat affected zone, cracking, and other discontinuities, while on the other hand, it shall provide a weld metal with acceptable properties [18].

2. Literature Review

2.1 Literature Search Methodology

This paper includes a standardized approach to present the countless research work done on joining similar or dissimilar stainless-steel joints with fusion and solid-state welding processes. The literature of the past few years was collected and efforts were made to define recent advances in welding of two variants of stainless steel which are stainless steel 316 grade and Duplex 2507 (UNS S32750). UNS 2507 duplex stainless- steel (SDSS) and low carbon Stainless-steel 316 grade were the base metals used to consider in this study, with their physical properties are shown in Table 1 and chemical composition (wt %) shown in Table 2.

Table 1. Physical Properties

Property	Duplex SS 2507	SS316 L
Crystal structure	FCC austenitic, BCC Ferritic	FCC austenitic

Property	Duplex SS 2507	SS316 L
Major alloying elements	Ni, Cr, Mo, N	Cr, Ni, Mo, Mn
Carbon content [wt%]	< 0.03	< 0.03
Thermal expansion [µm/m-°C]	13	16.0
Specific heat capacity [J/g-°C]	0.5	0.5
Thermal conductivity [W/m-K]	18	16.20
Yield strength [MPa]	551	290
Tensile strength [MPa]	799	558
Standard heat treatments	Annealing: 1052 °C	Annealing: 1040–1175 °C
Magnetism	Ferromagnetic	Paramagnetic
Density [g/cm3]	7.8	8.0

Table 2. Spectral analysis of 304 and 420 stainless steel plates. Material Elements (weight %)

Material	C	Si	Mn	Mo	S	P	V	N	Fe	Ni
SS 316	0.07	0.1	2.0	0.2	0.02	0.0211	0.102	0.0695	71.6	8.01
Duplex 2507	0.018	0.13	0.85	3.86	0.014	0.03	0.026	0.27	Bal.	6.72

SS 316 is resistant to thermal corrosion as well as mildly oxidizing and reducing conditions. It is also resistant to corrosion in contaminated aquatic environments. In the as-welded state, the alloy has outstanding resistance to intergranular corrosion. At cryogenic temperatures, SS 316 has exceptional strength and hardness. Stainless steel 316 is non-magnetic when annealed, but it can become mildly magnetic after cold working or welding. It is quickly welded and processed using traditional shop fabrication techniques. The impact strength is also high. Alloy 2507 is not recommended for applications that require long exposures to temperatures above 570°F because of the risk of a reduction in toughness.

Fig 1. Phase Diagram of Several Stainless-steel

2.2 Weldability:

When choosing a TIG welding machine, consider how much strength and complexity are needed for the job. It is also important to determine the actual number of such workers as well as the expected business for TIG welding. The next question is whether an AC or DC power source is needed. According to experts, aluminum and magnesium are two metals that are better welded using the power source's AC production. Steels and stainless steels are most often welded with direct current output. Use a hybrid AC/DC machine to solder a range of metals [19].

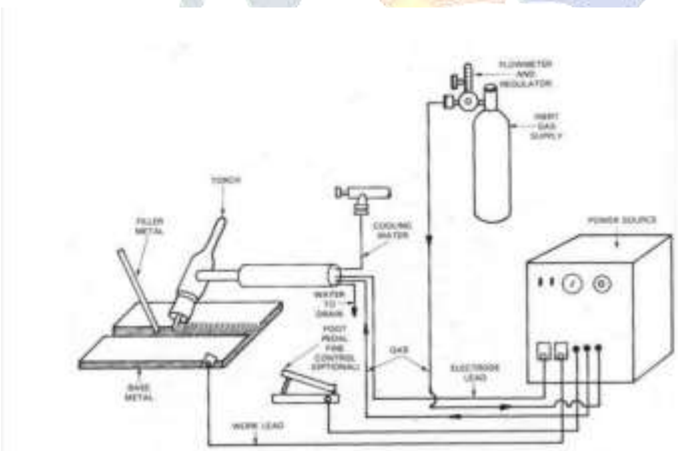

Fig. 2. TIG Welding Equipment

A portable welder is needed if the power source is shifted around the shop or from one location to another. Inverters and engine-driven welders are the two most common ways to achieve portability. Inverters weighing about 13 kg and equipped with handles for fast movement are now affordable. Where a welder does not have access to primary fuel, engine-driven machines are used. Land repairs, pipe drilling, and building work all necessitate the use of engine-driven power sources [20,21].

2.3 Corrosion and its behavior

In regular saline solution, potentiodynamic polarization curves of the base metal, weld metal, couple base/weld metal, and welded and heat-treated 316 SS were obtained.

Fig. 3. Welding distortions and defects

Fig. 4. Designated zone of weld, HAZ

The Tafel extrapolation procedure was used to calculate the corrosion current densities of different specimens from the potentiodynamic polarization curves. These findings are consistent with the corrosion potentials summarised in Table 2 for normal saline solution. Table 2 shows the standard deviations of corrosion current densities in parentheses. The linear polarisation system corrosion current densities are also mentioned. Table 2 shows that the base metal 316L SS has poorer corrosion resistance and hence higher corrosion current density (i_{corr}= 265 nA cm2) in standard saline solution than the weld metal (i_{corr}= 136 nA cm2) in the same conditions. Furthermore, the base metal has a lower open circuit potential in saline solution as compared to weld metal [22]. As base metal and weld metal are positioned adjacently in an electrolyte, the base metal is the anodic element that corrodes. Secondary phases are thought to harm pitting resistance because they or their environments are preferred sites for the initiation of co. The solution of secondary phases in weld metal appears to be the cause of the decrease in co-current density. The cooling process in TIG welding of the plates is so fast that the diffusion of alloying elements during welding is suppressed. Because the elements in the WM are uniformly distributed, both the δ and γ phases possess the same composition so that δ-ferrite in microstructure isn't detrimental to the corrosion resistance [23]. Because welds are more susceptible to corrosion, it is preferable to select a situation in which the welds are in the cathodic position, such as in the as-welded 316 SS sample. If the weld is in this cathodic position, the galvanic pile formed at the interface will not endanger the weld from other types of corrosion (crevice, pitting, or intergranular corrosion) caused by galvanic coupling [24].

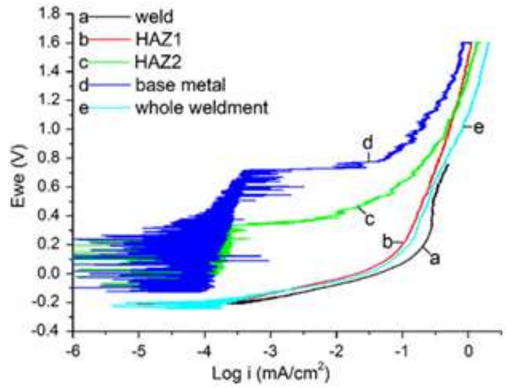

Fig.5. Potentiodynamic Polarisation test result

And 2507 Duplex is highly resistant to uniform corrosion as a formic and organic acid. Because of its high chromium and molybdenum content, 2507 is also resistant to inorganic acids, especially those containing chlorides. 2507 has greater corrosion tolerance in dilute sulfuric acid polluted with chloride ions than 904L[25]. Because of the possibility of localized and uniform corrosion, stainless steel of type 316 cannot be used in hydrochloric acid. 2507, on the other hand, can be found as dilute hydrochloric acid. Pitting does not have to be a concern in the region below the boundary in this figure 6, but crevices must be avoided. Because of the possibility of localized and uniform corrosion, stainless steel of type 316 (2.5 percent Mo) cannot be used in hydrochloric acid. 2507, on the other hand, can be found as dilute hydrochloric acid. Pitting does not have to be a concern in the region below the boundary in this figure, but crevices must be avoided [26].

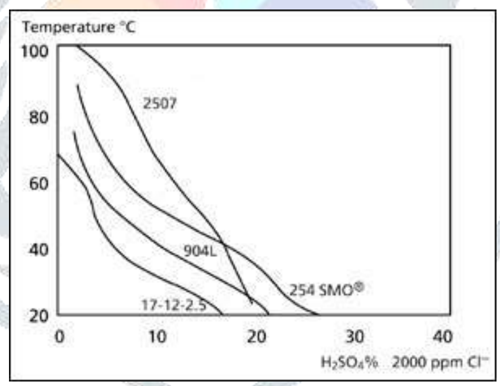

Fig. 6. Isocorrosion curves of sulfuric acid with an inclusion

Critical pitting temperature, CPT, was calculated in 6 percent FeCl3 using the ASTM G48A test program. The MTI-2 crevice former was used to calculate the critical crevice corrosion temperature, CCT. The processing time for both CPT and CCT experiments was 24 hours, and the same specimen was used for each CPT/CCT measurement as shown in Fig. 7. [37].

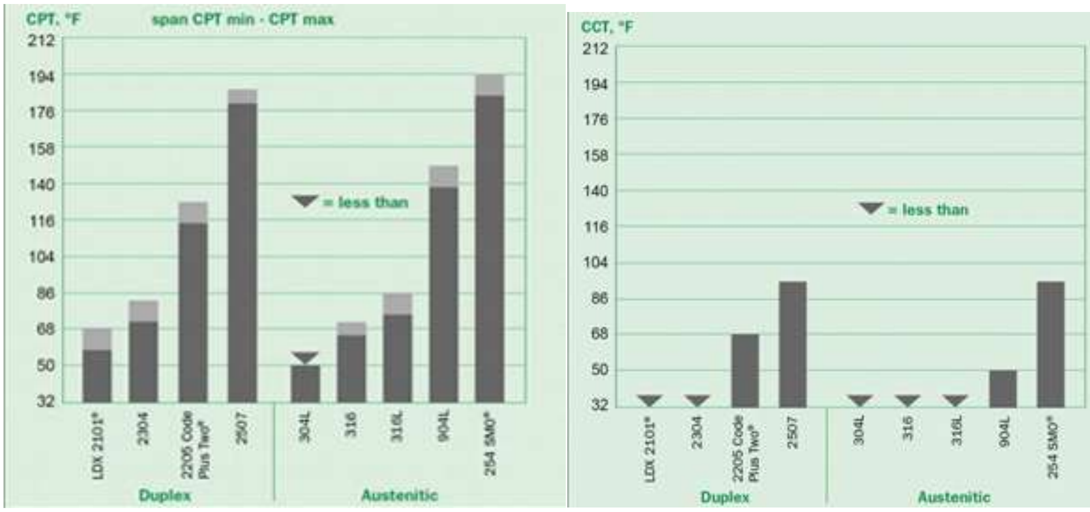

Fig. 7. Critical Pitting Temperature (CPT) spectrums

3. Results and discussion

The test research program's goal is to decide the effect of the parameters that affect Tensile Strength, weld metal into it. The experiments were carried out using an orthogonal array to track the effectiveness of current Welding, Arc Voltage, and Gas Flow Rate. These structural components are an internal and distinct part of the mechanism that has shaped and defined the incorporated functionality. The preparation of the specimen is a critical stage. After obtaining the specimen chemistry and obtaining authorization for further measures, we must prepare it for TIG welding. There are several methods for performing preparation on standard specimens, of which we chose to cut it first. A localized heat source that results in a narrow fusion region. A shallow welding pool with a very steady arc and a relaxed atmosphere. Spatter is removed, and since no flux is needed in the process, oxidation residues are avoided, simplifying any final cleaning activity. Excellent metallurgical efficiency, with precise regulation of penetration and weld form in all places, as well as sound and pore-free welds with very low electrode wear.

As a result of the welding process, the solidification of welding was columnar dendrites with a dual phased morphology. The mechanical properties of the joint are greater than the mechanical properties of the base metal as a result of the welding process. Since the weld joint is made of two dissimilar metals, the mechanical properties of the weld joint improve after welding, but the corrosion resistance begins to deteriorate [28].

The SS316 weldment's potentiodynamic polarisation test findings are seen in Fig. 3. The anodic current steadily improved with increasing potential for the weld and HAZ1 fields, suggesting the absence of passive films in these two zones. In other words, the weld and HAZ1 areas showed active corrosion activities. HAZ2 and the base metal fields, on the other hand, acted as passive metals, with current rising very slowly with increasing potential until the potential reached a critical value, at which point the current began to escalate suddenly. The sudden rise in current at this potential normally indicates the degradation of the passive coating on the metal surface and indicates localized corrosion, also known as pitting corrosion. The pitting potentials of HAZ and base metal areas were 0.3 V and 0.7 V, respectively [29]. The corrosion behavior of the entire weldment, including all four zones, was also checked in this study. The results showed that the entire SS316 and duplex 2507 weldment, like the weld region, acted as active metal. Comparing the corrosion habits of the chosen zones and the entire weldment, it was proposed that testing the entire weldment region would not discern the disparity in corrosion activity between the various zones on the weldment; the corrosion behavior of the weld zone and the HAZ1 zone could be so powerful that the passive activities of the HAZ2 and base metal zones were "overlooked". SEM was used to examine the surfaces during the electrochemical measurements [30].

Since welds are more susceptible to corrosion, it is best to select a situation in which the welds are in the cathodic role, as in the as-welded 316 SS and duplex 2507 study. The galvanic pile shaped at the interface would not endanger the weld from other types of corrosion (crevice, pitting, or intergranular corrosion) if the weld is in this cathodic place [31]. Unlike the conventional constant current technique, the solidification process is sometimes disrupted by the passage of two opposing currents, namely, peak current, and background current. Because of these waves, there is a cyclic eccentricity of energy input into the weld reservoir, which induces thermal fluctuation. The pulsed peak current deteriorates the solid-liquid interface as it progresses into the arc, making it more vulnerable to any interludes within the arc shape. When the current is re-accrued in the next pulse, the grain growth is halted and the growing dendrites re-melt. Furthermore, the current pulsing caused intermittent variations in the arc forces and hence additional fluid flows, which could tend to lower temperatures ahead of the solidifying interface. Furthermore, the temperature variations needed for pulsed welding cause a constant change in the size and shape of the weld pool, favoring the expansion of new grains [32].

As a result of the worldwide rapid growth of a large number of industrial sectors, high strength and corrosion-resistant materials, such as DSSs, are needed for long service life as well as higher efficiency in less time. In this series, stainless steel production technology has also improved significantly compared to the past, especially for DSS, which is a prominent and commonly used grade in many engineering applications that required welding and more science perspective to this field, but there are still some issues [33].

The combination of Duplex stainless steel with other popular steel alloys such as austenitic, ferritic, and carbon steel, as well as the standardization/recommendation of unique fillers. Formation of unwanted precipitates, increased distortion frequency, and residual stresses in high energy arc multi-pass welding (SMAW, GTAW, GMAW). High ferritization in the weld is consistent with a low energy arc phase (PAW, EBW, and laser). When using Friction Stir Welding to connect thick parts, there is a problem with uneven penetration. Higher welding speeds, such as 250 mm/min, produce the groove-like defect seen in Friction Stir Welding. Formation of voids and defects in welds joined through diffusion and explosive welding methods [34].

Rather than the above problems, a few researchers concluded that a proper range of welding conditions, cooling rate, and inter pass temperature provides proper phase balancing, even when combining dense parts in a single pass. Optimization of the cooling rate improves austenite formation even at very high cooling rates, and optimization of the inter pass temperature reduces corrosion susceptibility [35]. For future approaches, entering dense parts in vital service environments, specialized strategies such as hybrid, A-TIG, and PCGTAW would be a safer option. However, further research into the corrosion behavior of duplex alloys with these processes is needed. Similarly, high-strength, cost-effective FSW instruments must be designed and created. Some researchers have attempted solid-state joining of dissimilar metals (with DSSs), such as FSW, FW, and diffusion processes; some have succeeded, but the advice provided by these mechanisms is minimal [36]. Industrial demand still exists for the development of cost-effective electrodes with improved mechanical and corrosion resistance. Optimization of welding conditions, precise analysis of cooling rate inter pass temperature, and in-site characterization during welding are needed to join thick section duplex alloys and dissimilar metal combinations, the potential understanding is on-site corrosion characteristic research and material life estimation. Future researchers will face a significant challenge in analyzing weld zone/reheat zone/HAZ zone texture action, the impact of grain orientation on corrosion behavior, welded zone strain analysis, residual tension, and cryogenic temperature studies [37].

4. Conclusion

This study details the finding that looked at the effects of GTAW process parameters, filler metals chemical composition on the joint properties on dissimilar joints of stainless steel 316 and duplex stainless steel UNS S32507 joints and analyze the corrosion behavior on selected zones.

Different corrosion habits were observed in the chosen areas. The weld and HAZ1 zones of a 316 stainless steel weldment were active metal, while the HAZ2 and base metal zones were passive metal. The entire 316 stainless steel weldment, including all four zones, had comparable corrosion activity to the weld zone. The stainless-steel weldment made of 2507 duplex stainless steel was less resistant to pitting corrosion than the stainless steel 316 weldment. Different corrosion behaviors were caused by different surface environments and microstructures at the zones. Standard testing conditions on stainless steel weldments could be used using this process, and the method was successful in distinguishing the various corrosion habits of different zones on stainless steel weldments.

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