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Recent findings on corrosion of ferritic stainless steel weldments: A review

ABSTRACT

This study covers the review of the degradation of ferritic stainless-steel weldments between 2015 and 2022. The industrial and automotive sectors make extensive use of ferritic stainless steel (FSS) due to its superior oxidation and corrosion resistance, low price, high thermal conductivity, and low thermal expansion. However, it has been reported that ferritic stainless steel is harder to weld than austenitic stainless steel and that doing so would probably result in a weaker welded joint owing to the coarsening of grains high welding temperatures. According to past research, the amount of heat applied during the welding procedure affected how soon the FSS (409 M) weldment degraded after being exposed to NaCl (3.5%) medium. The coarsening of the grains was considered to be the cause of this. When the shielding gas' CO_2 content increased, the intergranular corrosion of the FSS weld metal was found to increase. Welds made with the ER430LNb filler metal had significantly lower intergranular corrosion of FSS (AISI 441) than those made with the ER430Ti filler metal. It was discovered that boiling Cu-$CuSO_4$ – 50% H_2SO_4 solution increased the corrosion rate for the FSS (AISI 430) weldment more than boiling 40% HNO_3 Solution. Weldments made of FSS (AISI 430) were found to be negatively affected by the Cu-$CuSO_4$ – 50% H_2SO_4 environment in terms of intergranular corrosion attack.
Keywords: *Corrosion, weldment, ferritic stainless steel, welding, FSS*

1. INTRODUCTION

A ferritic stainless steel (FSS) is a kind of steel that consists of mainly chromium and iron with traces of other elements like selenium, sulphur, carbon, and aluminium to either increase the ability in which the material is machined or reduce high-temperature precipitation of the austenite [1]. For the ferritic stainless steels, the carbon content is kept low (less than 0.08 %) and the content of chromium can be between 10.50 and 30.00% [2]. They are known as ferritic alloys because, at all temperatures, they principally have ferritic microstructures and cannot be made harder via heat treatment and quenching. Only chromium is present as the primary metallic alloying element in some ferritic grades, which contain molybdenum up to 4.0%. They are typically constrained to relatively thin sections as a result of weak weld toughness and low high-temperature strength.

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Ferritic stainless steels are favoured over austenitic stainless steels in situations where chloride-induced stress corrosion cracking (SCC) is widespread because of their resistance to SCC [3]. However, they are more difficult to weld than austenitic stainless steels and consequently more prone to producing weaker welded joints owing to grain coarsening at elevated welding temperatures [1]. The welding of ferritic stainless steels can be done without a filler metal (autogenously) or with a matching filler metal or with an austenitic stainless steel filler metal or with a high-nickel filler alloy. The common welding techniques employed in joining ferritic stainless steels are mainly the arc welding techniques such as gas-tungsten arc welding (GTAW), gas-metal arc welding (GMAW), shielded-metal arc welding (SMAW) and plasma arc welding (PAW). Submerged arc welding is not appropriate for the majority of ferritic stainless steel grades, whereas friction welding, resistance welding, electron beam welding, and laser welding are less often utilized techniques. Due to such properties as their relatively higher thermal conductivity and lower thermal expansion, excellent oxidation and corrosion resistance, and relatively lower cost compared to austenitic stainless steels, ferritic stainless steels find extensive application in the automotive, kitchen appliances, and manufacturing industries [4]. They offer very good degradation resistance in chloride medium [5]. The ferritic stainless steel grades are employed in the making of boilers, water heaters, and the exhaust system of vehicles even though they do not have the same great weldability as austenitic stainless steel. To achieve the desired mechanical properties, ferritic stainless steels can be laser welded without the need for shielding gas. Yet, using a shielding gas can enhance the weld area's general resistance to corrosion [6]. Type 409 of FSS with 12% Cr has been reported to be comparatively cheaper and has strong forging and welding properties. If a ductile-to-brittle transition temperature (DBTT) at room temperature or below is required, a maximum thickness of about 3.8mm is advised [6].

The ferritic stainless steels have a variety of welding concerns. Despite their low carbon content, fast cooling can cause carbide to precipitate at grain boundaries, "sensitizing" the steel and making it more vulnerable to inter-crystalline corrosion. However, this unpleasant condition has been reduced as a result of new developments in extremely low carbon, titanium, or niobium grades in recent years [7].

The objectives of this current work are to:

(i) evaluate recent studies on the corrosion of welded FSS joints in various corrosion-induced conditions;

(ii) identify knowledge gaps currently present in the subject field; and

(iii) provide suggestions for filling the identified knowledge gaps.

2. REVIEW OF SELECTED TECHNIQUES FOR WELDING FERRITIC STAINLESS STEELS AND WELD DECAY

2.1. FSS weldments produced by shielded metal arc welding (SMAW)

Shielded metal arc welding (SMAW) is the welding technique that is typically used to join ferritic stainless steel. In this process, heat from an electric arc that is maintained between the tip of a consumable electrode and the surface of the base material in the joint being welded results in the coalescence of metals [8]. As the electrode is brought into contact with the workpiece, an electric arc is produced, signalling the start of the SMAW procedure. To create a pool of molten steel, the metal must first melt and then be heated through the electrode. The workpiece is moved along with the weld puddle while filler metal is added. There must be filler metal added to the weld when SMAW is employed. Metal filler comes in a wide variety of forms, each with a special set of characteristics. The ER6010, ER7018, and ER8028 are among the most commonly used varieties [9]. Fig. 1 depicts a schematic representation of shielding metal arc welding.

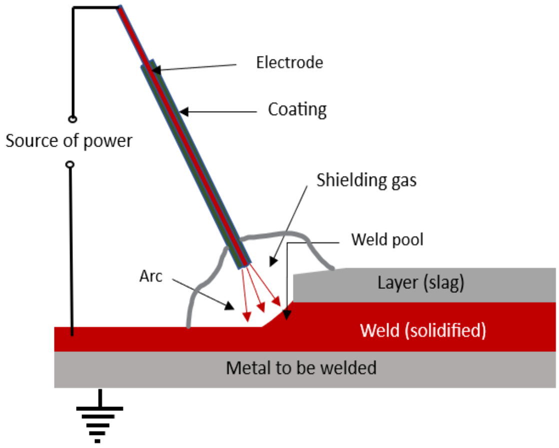

Figure 1. Schematic illustration of shielding metal arc welding [10]

Slika 1. Šematski prikaz zavarivanja zaštitnog metala [10]

The austenitic and ferritic (nuclear grade) stainless steel welded joints have been studied using SMAW [11]. It was reported that the toughness (impact) of the dissimilar metal weld was found to be less than that of each of the individual base metals. In another study, the SMAW process was employed to perform undersea welding of an austenitic-ferritic joint [12]. The researchers discovered that the root bending performance of the weld was not satisfactory. They also found that the microcracks, induced by the entrapped hydrogen in the weldment were the initiation sites for fracture.

2.2. FSS weldments produced by gas metal arc welding (GMAW)

Gas metal arc welding (GMAW) is another method used to join ferritic stainless steel. During welding, an arc is generated between a consumable metal electrode and the workpiece with the use of an externally supplied gaseous shield of inert gas, such as argon and/or helium [13]. According to Vairamani et al. [14] a consumable wire electrode distinguishes metal inert gas (MIG) welding from metal active gas (MAG) welding, which are both commonly referred to as GMAW. In this procedure, an arc is created between the workpiece and an electrode made of metal wire that is continuously supplied into the arc. Drive rollers push the wire through a flexible conduit in the hose package to the welding gun from where it is supplied on a reel. The contact tube of the welding gun transmits electrical energy from the arc to the wire. Typically, the workpiece is linked to the negative pole of the power source and the contact tube to the positive pole. The circuit is finished when the arc is struck. The weld pool and arc are shielded by gas that is supplied by the gas nozzle that surrounds the contact tube [14]. Fig. 2 shows a representation of the metal arc welding process.

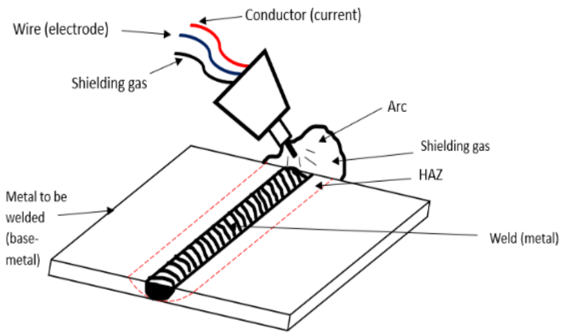

Figure 2. Gas metal arc welding process [15,16]

Slika 2. Proces zavarivanja gasnim metalom [15,16]

FSS (30Cr–4Mo) weldments produced by GMAW (double-pulsed) have been investigated [17]. The authors found that towards the fusion zone's centreline, columnar dendrites changed into equiaxed dendrites and some scattered white Nb-rich carbides were seen within the fusion zone [17]. A study to unravel the magnetic behaviour of FSS in response to GMAW has been undertaken [18]. It was reported that the coarser grain size of the heat-affected zone made it to be more responsive to the magnetic Barkhausen noise when compared to the finer grains of the base metal.

2.3. Dissimilar metal weld joint

Many studies have been done on the dissimilar joining of FSS to other stainless steel kinds, primarily austenitic stainless steel, according to the available literature. Due to several difficulties that are inherently present in dissimilar joints, including mismatch, metallurgical corrosion, carbon migration, and differences in coefficients of thermal expansion, the research on these joints is important [19]. In their investigation of a dissimilar weld joining of SA508.GR.3l.1 ferritic steel and SS304L made using Iconel 182 nickel-base consumables, Rathod et al. [20] observed that all of the fabricated joints fractured at the weldment because of metallurgical degradation that produced carbide precipitation. The crystalline structural mismatch between FSS and ASS, which determines the thermo-mechanical, corrosion, and physical properties, also affects the welded joint's characteristics in dissimilar welding [21]. Akrem et al. [22] created a joint with three Inconel interlayers in their study on the creep behaviour of dissimilar weld joints made of P91 and AISI 304. This joint had a longer rupture life than a single-layer weld joint. The longer rupture life was ascribed to the progressive change in the coefficient of heat expansion between P91 steel and AISI 304 stainless steel.

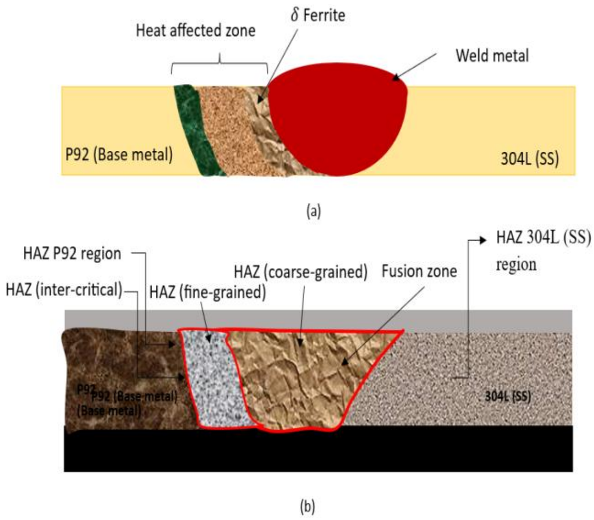

Figure 3 (a) Schematic illustration of different regions created in the dissimilar SS304 L and P92 welded joints. (b) A macrograph of the welded joint demonstrating the many zones created throughout the joint [23]

Slika 3. a) Šematska ilustracija različitih regiona stvorenih u različitim zavarenim spojevima SS304 L i P92. (b) Makrograf zavarenog spoja koji pokazuje mnoge zone stvorene u celom spoju [23]

The strong heat conductivity of P92 led to a characteristic feature at the HAZ in the dissimilar welded joint between the P92 material and SS 304L steel, as seen in Fig. 3. The three separate zones that make up the HAZ at P92—coarse-grained HAZ, fine-grained HAZ, and inter-critical HAZ—offer unique microstructure and mechanical characteristics [22-24].

2.4. Weld decay of ferritic stainless steel

Weld decay is a kind of intergranular corrosion that often affects stainless steel and results from sensitization in the heat-affected zone during the welding process [25-26]. Chromium is depleted in the area surrounding grain borders, causing sensitization, as a result of the development of chromium carbide ($Cr_{23}C_6$) at grain boundaries [27]. Localized galvanic cells appear as a result of chromium deficiency. The area will become sensitive to corrosion, leading to intergranular corrosion, if this depletion lowers the chromium level below the essential 12 wt.% needed to maintain a protective passive coating [26]. In Fig. 4, a schematic representation of the weld decay of a stainless-steel weld is shown.

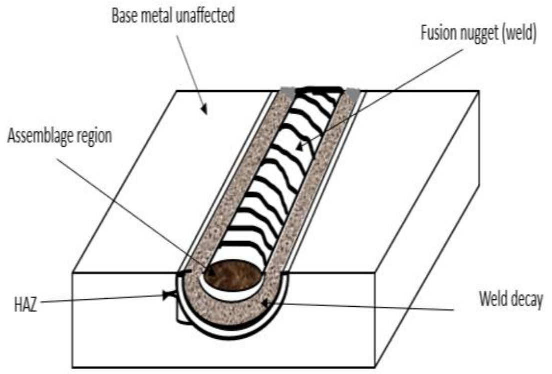

Figure 4. Schematic illustration of stainless steel's weld decay [25]
Slika 4. Šematski prikaz propadanja šava od nerđajućeg čelika [25]

Weld decay develops when a material is overheated at temperatures of around 700°C over an extended period. It frequently occurs during welding or after ineffective heat treatment. Weld degradation is the term for the corrosion that results when such small-scale galvanic cells are created during welding.

3. OVERVIEW OF RECENT FINDINGS ON CORROSION OF FERRITIC STAINLESS-STEEL (FSS) WELDMENTS

Recent studies on the deterioration of ferritic stainless steel welded joints in various service conditions have been appraised and reported in this section. The summary of the various observations reported by different scholars is presented in Table 1.

Table 1. An overview of pertinent studies on the corrosion of ferritic stainless-steel welded joints

Tabela 1. Pregled relevantnih studija o koroziji feritnog zavarenog spoja od nerđajućeg čelika

The welded material	Utilized welding method	The material used as a filler (wire)	The technique used for studying corrosion	Utilized corrosive medium	Remarks on the corrosion resistance of welds	Ref.
FSS (409M)	GMAW, GTAW & SMAW	ER-308L	WL	NaCl (3.5%)	Welded structures and the creation of wider HAZ with increasing welding heat input were responsible for the increased rate of corrosion.	[28]
LCS & FSS	Laser	-	PDP	NaCl (1 M)	High corrosion current density at the LCS-FSS interface indicated the occurrence of galvanic corrosion at the dissimilar weld joint.	[29]
FSS (430)	AFTIGW & conventional TIGW	Rod of tungsten electrode thoriated by 2%	PDP	NaCl (3.5%)	The corrosion potential for the weldment obtained by the AFTIGW process was found to give a more positive value than that produced by the TIGW process.	[30]
AISI 430 (un-stabilized) & AISI 430Ti (titanium-stabilized)	Rapid laser cladding	-	Strauß test (DIN EN ISO 3651-2)	H_2SO_4 (1.84 M) & Penta-hydrate copper-sulphate (750 mL)	The weldment experienced intergranular corrosion as a result of chromium carbide precipitation in the unstabilized AISI 430 FSS.	[31]
FSS AISI (410S)	Friction (stir)	-	DL-EPR	H_2SO_4 (0.1 M) + Na_2SO_4 (0.4 M) and KSCN (1000 mg/L)	Using the FSW technique and welding AISI 410S steel at 450 rpm with little heat input, joints with superior intergranular corrosion susceptibility were produced.	[32]
SFSS Cr26Mo3.5	P-TIG & Laser	-	EIS	NaCl (1 M)	The corrosion resistance of FSS welded joints decreased with an increase in heat input of the welding process.	[33]

AFSS (UNS 32205) & FSS (AISI 430)	Arc (welding)	Duplex E2209 and Austenitic (E309LMo) electrodes	DL-EPR, EIS & PDP	H_2SO_4/NaCl	The heat-affected zone of AISI 430 showed more intergranular corrosion.	[34]
FSS (T4003)	CMT	ER308LSi	PDP	NaCl (3.5 %)	The creation of a fine grain-layer increased the surface corrosion resistance of welded joints following surface ultrasonic rolling treatment.	[35]
AISI 441 FSS	GMAW	ER430LNb and ER430Ti	DL-EPR	KSCN (0.01 M) & H_2SO_4 (0.05 M)	With the use of ER430Ti filler metal, it was found that the weld metal became more prone to corrosion as the CO_2 level of the shielding gas increased.	[36]
FSS (430)	GTAW	-	A262-E (ASTM) & A262-C (ASTM)	40% HNO_3 & Cu-$CuSO_4$ with 50% H_2SO_4	It was observed that at 950^0C, an intergranular corrosion attack occurred on the base metal as well as the weldment.	[37]
409M FSS	SMAW	-	DL-EPR	H_2SO_4 (0.5 M) with the addition of NH_4SCN (0.01 M)	The propensity for the occurrence of intergranular corrosion increased with heat input.	[38]
409M FSS	SMAW	-	DL-EPR	H_2SO_4 (0.5 M) with the addition of NH_4SCN (0.01 M)	Increasing the number of passes led to grain growth in the HAZ and caused the width of the HAZ to expand leading to high corrosion rates.	[39]
AISI 430Ti (stabilized) FSS and AISI 430 (unstabilized) FSS	Laser welding	-	Strauß-test on a basis of DIN EN ISO 3651-2	H_2SO_4 (aq) and Cu $SO_4.5H_2O$ (aq)	Weld metal produced from AISI 430Ti (stabilized) FSS base metal experienced more intergranular attack compared to that of AISI 430 (unstabilized) FSS material.	[40]
439 FSS	TIGW process	308L filler electrode	DL-EPR method	0.5 M H_2SO_4 and 0.01 M NH_4SCN	Weldments produced with higher heat input exhibited better resistance to intergranular corrosion compared to weld metal produced from low heat input.	[41]
439 FSS	TIGW process	308 L, 309 L, and 316 L filler rods	DL-EPR method	0.5 M H_2SO_4 and 0.01 M NH_4SCN	Weld metals produced from 308 L filler rods exhibited the highest resistance to intergranular corrosion while 316 L weldments were relatively more prone to intergranular corrosion.	[42]

Ambode et al. [28] studied the influence of different arc welding processes and varied heat input on the corrosion properties of 409M ferritic stainless steel (FSS). Shielded metal arc welding, SMAW (with heat inputs of 776.25, 862.5 and 948.75J/mm), gas metal arc welding, GMAW (with heat inputs of 648, 720 and 792J/mm) and tungsten inert gas welding, TIGW (with heat inputs of 621, 690 and 759J/mm) processes were employed in the production of FSS weldments using 308L welding rod. The corrosion behaviour of the joints was studied in sodium chloride solution for nine (9) days of exposure time. The weight loss method was used to determine the corrosion rates. The width of the HAZ was observed to vary with the welding processes with SMAW and TIGW having the largest and smallest heat-affected zones (HAZs) respectively. It was observed that the corrosion rate of the FSS welded joints increased with the width of HAZ and the heat input for each welding process. This was attributed to the characteristic grain coarsening effect associated with the heat-affected zone (HAZ) since the width of HAZ increased with heat input. It was concluded that the corrosion rates of FSS weldments in NaCl (3.5wt.%) solution increased by varying the welding process from TIGW to GMAW to SMAW. Wu et al. [29] studied the corrosion behaviour of a dissimilar joint comprising low carbon steel (LCS) and FSS in NaCl solution (1 M). High corrosion rates were observed at LCS-FSS joint interface due to the galvanic reaction of the base metal with the weldment.

Touileb et al. [30] studied the impact of activated-flux tungsten inert gas welding (AFTIGW) on the corrosion of 430 FSS weld joints. The corrosive medium was NaCl (3.5 %) solution and the corrosion rates were obtained from a potentiodynamic polarization test. It was reported that the weldment that was produced by AFTIGW gave a better corrosion resistance when compared to the weldment obtained from the conventional TIGW technique. The improved corrosion resistance observed in FSS joints produced by the AFTIGW process was attributed to the presence of active fluxes in FSS base metal which excludes chemical inhomogeneity in the weldment. Comparing AFTIGW with TIGW joints, Vidyarthy et al. [43] added that joints produced from TIGW are often liable to stress corrosion cracking due to the overlapping of weld beads associated with the intersecting isotherm.

In a recent study, Sommer et al. [31] investigated the intergranular corrosion of unstabilized AISI 430 FSS weldment produced by laser cladding at high speed. It is observed that the FSS weld joint was prone to intergranular corrosion due to the segregation of the alloy elements within the weld metal zone. On the other hand, the study maintained that joints made from stabilized FSS (AISI 430 Ti) were more resistant to intergranular corrosion. These observations, therefore, suggest that the effective resistance to corrosion exhibited by the titanium stabilized FSS was because of the inability of titanium carbide and titanium nitride precipitates around the clad to form galvanic couples. Caetano et al. [32] studied the intergranular corrosion of stir friction welded FSS AISI (410S) joints. It is observed from corrosion test results obtained from double-loop electrochemical potentiokinetic reactivation, that the weldments were prone to sensitization and intergranular corrosion following the precipitation of Cr_2N within the ferrite matrix. This observation agrees with the findings of many authors including Lakshminarayanan et al. [44], Kim et al. [45] and Kim et al. [46], where it was confirmed that precipitation of chromium carbide is the main cause of intergranular corrosion in FSS welded joints. Caetano et al. [32] however suggested a remedy to intergranular corrosion susceptibility by conducting the friction stir welding at 450 rpm while maintaining little heat input. Hu et al. [33] studied the corrosion resistance of weldments produced by the laser and pulse tungsten inert gas (P-TIG) welding processes in NaCl (1 M) corrosive medium. Precipitation of nitrides and carbides of titanium and niobium in both HAZ and weld metal zone was observed. The effects of these precipitates on the corrosion properties of the FSS weldments were not reported. The study rather observed that the corrosion resistance of the joints produced by the laser welding process was higher compared to joints produced by the pulse tungsten inert gas welding process. It was explained that the weldments produced by laser welding showed suppression of grain growth due to relatively lower heat input and higher heat concentration. The study, therefore, observed that the resistance to corrosion of FSS weldment reduced with an increase in the applied welding heat input. In another study, Verma et al. [34] reported the corrosion behaviour of weldments obtained by arc welding of Austeno-ferritic stainless steel (AFSS) and AISI 430 FSS base materials. They reported that the dissimilar weld metal was prone to intergranular corrosion in the H_2SO_4/NaCl corrosive medium and this was attributed to carbide precipitation in the weld metal. AISI 430 FSS base metal had a more sensitization effect because of their higher carbon content and consequent high chromium depletion. The corrosion behaviour of T4003 FSS weldment subjected to surface ultrasonic rolling treatment has been studied and reported by Liu et al. [35]. It is observed that ultrasonic rolling treatment conducted on the weld surface improved the corrosion resistance of the weld metal. Filho et al. [36], studied the intergranular corrosion behaviour of AISI 441 FSS weldment under varied compositions of the shielding gas. It was observed that the intergranular corrosion of the weldments increased with the CO_2 content in the shielding gas. Rajamurugan et al. [37] investigated the influence of varied welding conditions on the corrosion behaviour of FSS (AISI 430) weldment. The specimen for the corrosion test was placed on an electrically heated plate in the presence of 40 % HNO_3 and Cu-$CuSO_4$ with 50 % H_2SO_4 media. The weight loss method was used to evaluate the corrosion rates of the weld metal samples. It was observed that both the weldment and base metal FSS (AISI 430) were susceptible to intergranular corrosion at an elevated temperature (950 ^{0}C). The researchers also noted that the weld metal samples exposed to boiling Cu-$CuSO_4$ with 50 % H_2SO_4 medium had higher corrosion rates compared to the weldment immersed in boiling 40 % HNO_3 solution. The intergranular corrosion attack on FSS (AISI 430) weldments were aggravated by the Cu-$CuSO_4$ with 50 % H_2SO_4 corrosive solution [37].

Ambade et al. [38] studied the influence of welding heat input on the corrosion behaviour of 409M FSS weldment. It is observed that the width of HAZ increased with heat input. Consequently, the study noted that the propensity for the occurrence of intergranular corrosion increased with heat input. This was attributed to the precipitation of chromium carbide at grain boundaries and the characteristic grain growth structures in the HAZ associated with high welding heat inputs. In another study, Ambade et al. [39] investigated the influence of several welding passes on the corrosion behaviour of 409M FSS weldment. Weldments of different samples were produced by varying the number of weld passes during the SMAW process. The electrochemical potentiokinetic reactivation (DL-EPR) technique was employed to determine the corrosion rates of the various test samples. It was observed that the tendency for intergranular corrosion of the weld metals increased with the number of passes due to the precipitation of chromium carbide at grain boundaries which accumulated with an increasing number of passes and led to a sensitization effect. It is noted that increasing the number of passes also leads to grain growth in the HAZ and causes the width of the HAZ to expand leading to high corrosion rates.

Sommer et al. [40] studied the intergranular corrosion behaviour of AISI 430 (unstabilized) and AISI 430Ti (stabilized) FSS weld metals, produced by the laser welding process. The weldments were exposed to H_2SO_4 (aq) and Cu $SO_4.5H_2O$ (aq) solutions for 20hrs. It is observed that the corrosion behaviour of the AISI 430 (unstabilized) and AISI 430Ti (stabilized) FSS weld metals is sensitive to the type of precipitate formed in the weldments. In AISI 430 (unstabilized) FSS weldment, precipitates of chromium were reported to form at the grain boundaries. For the AISI 430Ti (stabilized) FSS weld metals, a diminution of chromium was observed at grain boundaries along with the formation of precipitates of titanium in the weld metal. Consequently, both AISI 430 (unstabilized) and AISI 430Ti (stabilized) weld metals were susceptible to intergranular corrosion. It is however noted that the weld metal produced from AISI 430Ti (stabilized) FSS base metal experienced more intergranular attack compared to that of AISI 430 (unstabilized) FSS material. This was attributed to the lessening of chromium at grain boundaries of AISI 430Ti (stabilized) weld metal.

Gupta et al. [41] studied the effect of heat input on the corrosion behaviour of Ti-stabilized 439 FSS using the TIGW process. The weldments were exposed to the corrosive media containing 0.5 M H_2SO_4 and 0.01 M NH_4SCN solutions at ambient temperature while the DL-EPR method was used to measure the corrosion rates in terms of their inclination to intergranular cracking. The width of the HAZ was observed to expand with an increase in heat input. Weldments produced with low heat input had a higher volume fraction of retained austenite in the weld metal structure compared to weld metal produced with high heat input. It was explained that the higher the volume fraction of retained austenite, the higher will be the number of grain boundaries resulting in a higher number of sensitization sites. Consequently, the weldments produced with higher heat input exhibited better resistance to intergranular corrosion vis-a-vis the weld metal produced from low heat input.

In another work, Gupta et al. [42] studied the effect of electrode types on the corrosion behaviour of Ti-stabilized 439 FSS. TIGW process was used to produce the weldments with different filler rods (308 L, 309 L, and 316 L). It is observed that the weldments produced from the 316 L filler rod exhibited a higher fraction of retained austenite compared to 308 L and 309 L weldments. Also, 309 L weldments had a higher volume fraction of retained austenite than weldments produced from 308 L filler rods. Weld metals produced from 308 L filler rods exhibited the highest resistance to intergranular corrosion while 316 L weldments were found to be more prone to intergranular corrosion. The study confirmed that the propensity to intergranular corrosion of FSS weldment is sensitive to the volume fraction of the retained austenite in the weld metal.

4. IDENTIFIED GAPS IN KNOWLEDGE AND RECOMMENDATIONS FOR FUTURE STUDIES

Reviewing earlier research on the corrosion of ferritic stainless steel weldments gives various insights into how process variables including welding speed, heat input, electrode composition, and welding procedure affect the corrosion of the welded FSS joint. However, the identified gaps in knowledge and recommendations listed below may spur and refocus further research on the subject matter, vide:

- There is limited information concerning the use of inhibitors to deter the corrosion of ferritic stainless-steel weldments. It is advised that future studies consider the use of green inhibitors [47] to protect the FSS weldment from degradation in numerous corrosive media.

- Studies have attributed the reduction in corrosion resistance of FSS weldment to the increase in the heat input during welding [33, 38] while according to Gupta et al. [41], the opposite trend is true. There is limited knowledge concerning the optimum heat input values or range of values to produce excellent corrosion-resistant FSS welded joints for different grades of FSSs. It is recommended that future studies be carried out to investigate in specific terms, the values of welding heat inputs that are suitable for producing outstanding corrosion-resistant FSS weldments, and by extension, dissimilar FSS welded joints.
- There is limited knowledge about the model for predicting the FSS weldment's corrosion rate occasioned by the effects of the corrosive environment, time of exposure and other welding conditions like the length of arc, current, angle, and speed of welding. It is recommended that future studies be geared towards the use of predicted models inspired by the ANN (artificial neural network) and multiple regression protocols earlier reported [48-54] for the inhibition of corrosion of mild steel in an acidic medium.

5. CONCLUSION

The following findings may be derived after reviewing earlier studies on the corrosion of ferritic stainless-steel weldment from 2015 to 2022:

- It was discovered that the amount of heat applied during the welding process affected the pace at which the FSS (409 M) weldment corroded when it was subjected to NaCl (3.5%) medium.
- The intergranular corrosion of the FSS weld metal increased as the CO_2 level of the shielding gas increased and welds obtained with the ER430LNb filler metal had much reduced intergranular corrosion of FSS (AISI 441) than those produced with the ER430Ti filler metal.
- The corrosion rate for the FSS (AISI 430) weldment generated by the GTAW technique was found to be greater in boiling Cu-$CuSO_4$-50% H_2SO_4 solution than in boiling 40% HNO_3 Solution. The intergranular corrosion attacks on FSS (AISI 430) weldments were found to be negatively impacted by the Cu-$CuSO_4$-50% H_2SO_4 environment.
- According to the findings emanating from the investigation on how the number of welding passes affected the corrosion behaviour of a 409M FSS weldment, it was discovered that the number of passes increased the tendency for intergranular corrosion of the weld metals. Consequently, the sources of this development were identified as grain expansion in the HAZ and chromium carbide production at grain borders.

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IZVOD

NOVI NALAZI O KOROZIJI FERITNIH VAROVA OD NERDJAJUCEG CELIKA – PREGLED

Ova studija pokriva pregled degradacije feritnih zavarenih spojeva od nerđajućeg čelika između 2015. i 2022. Industrijski i automobilski sektor u velikoj meri koriste feritni nerđajući čelik (FSS) zbog njegove superiorne otpornosti na oksidaciju i koroziju, niske cene, visoke toplotne provodljivosti, i nisko toplotno širenje. Međutim, prijavljeno je da je feritni nerđajući čelik teže zavariti od austenitnog nerđajućeg čelika i da bi to verovatno rezultiralo slabijim zavarenim spojem jer visoke temperature zavarivanja ogrubljuju zrno. Prema prošlim istraživanjima, količina toplote primenjene tokom postupka zavarivanja uticala je na to koliko brzo se FSS (409 M) zavar degradirao nakon izlaganja medijumu NaCl (3,5%). Smatralo se da je uzrok tome ugrušavanje zrna. Kada se povećao sadržaj CO_2 u zaštitnom gasu, otkriveno je da se povećava intergranularna korozija metala šava FSS. Zavari napravljeni dodatnim metalom ER430LNb imali su značajno manju intergranularnu koroziju FSS (AISI 441) od onih napravljenih sa dodatnim metalom ER430Ti. Otkriveno je da ključanje rastvora Cu-$CuSO_4$ – 50% H_2SO_4 povećava stopu korozije za FSS (AISI 430) zavar više od ključanja 40% rastvora HNO_3. Utvrđeno je da na zavare napravljene od FSS (AISI 430) negativno utiče okruženje Cu-$CuSO_4$ – 50% H_2SO_4 u smislu napada intergranularne korozije.

***Ključne reči**: Korozija, zavarivanje, feritni nerđajući čelik, zavarivanje, FSS*

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