Effect of Weld Process Parameter on Weldability and Corrosion Behavior of Ferritic Stainless Steels: A Review

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Abstract

The impetus nickel supply shortfall and incessant change in its expense brought about getting the consideration of specialists to affect different options of stainless steel which contains less measure of nickel as its alloying component. Among the different existing stainless steel grades, austenitic stainless steels (ASS) are used in roughly 60-70 % of uses, yet ASS requires nickel as its major resulting. One of the better choices to supplant austenitic stainless steel is ferritic grades, which contain less nickel and have very much like execution at a generally lower cost. The current investigation is an endeavor to feature the different welding strategies (fusion/solid-state) which are used most, for the joining of these ferritic stainless steel (FSS) grades. The writing affirms that because of the metallurgical issues related to fusion welding processes, solid-state joining processes, for example, forge welding, pressure welding, ultrasonic welding and friction stir welding (FSW), and so forth are educated to be utilized for joining concerning ferritic stainless steels depending their appropriateness. Furthermore, the corrosion-related perspectives should likewise be dealt with during the utilization of these prepares for different purposes.

Keywords: Low Ni alloy, FSS, Joining processes, Corrosion Behavior

1. Introduction

In light of a legitimate concern for their excellent corrosion resistance, great mechanical properties at a raised temperature, and better weldability, austenitic stainless steel have customarily been the most used widely grade for various modern applications [1]. Significant constituents of austenitic stainless steels are chromium (Cr) and nickel (Ni). These alloying components strengthen the resistance from corrosion, the maintainability of steels at higher temperatures, and different properties. Moreover, Ni-based stainless steels are more scratch-protected, owing to their normal work solidifying properties. However, the issues related to nickel accessibility and its cost variation permit the advancement of other substitute evaluations, for example, ferritic stainless steel. These steel are notable for their excellent resistance against stress corrosion cracking resistance, oxidation at high temperature, pitting, and crevice corrosion in chloride conditions [2]. Also, less expansion and contraction because of temperature change, remarkable showdown against oxidation at raised temperature and stress corrosion cracking upgrades the use of ferritic stainless steels in different ventures fundamentally covering automobile sector (exhaust pipes, exhaust systems, suppressors, tailpipes, and so forth), the petrochemical area (processing plants), food preparing, brewery and wine-production hardware [3]. Decrease in the concentration of interstitial components, for example, carbon and nitrogen with the expansion of stabilizing components like molybdenum, titanium, niobium, and others upgrade the resistance against corrosion/erosion and it helps ferritic stainless steel grades to be even better than the greater part of the austenitic stainless steel grades [4]. A further consideration is expected to recognize better strategies for joining these materials either comparative or unique. These steel can be easily joined by fusion welding processes, while studies show that the heat produced during fusion welding processes prompts coarsening of grains as quick cooling yields the solidification of molten metal to ferrite phase without any intermediate phase transformation. Thus, the conventional liquid-solid welding processes such as fusion welding decreases the useful mechanical properties such as ductility, impact strength, and corrosion resistance [5]

2. Literature Review

2.1 Welding processes:

Among the various solid-state welding processes, friction stir welding proved to be a successful welding process to develop defects-free weld of FSS grade 409 utilizing a polycrystalline cubic boron nitride (PCBN) tool. The microstructure analysis displayed a fine-grained disseminated stir zone (SZ). Further, investigation reveals a considerable rise in the existence of the low angle grain boundary in SZ when compared with a base metal (BM). It has also been detected that increasing the plunging depth decreases the size of the grain and improves hardness [6]. Keeping the friction stir welding tool rotational speed constant and the welding speed as a variable, various tests comprising optical microscopy, electron back-scattered diffraction (EBSD), scanning electron microscopy (SEM), impact test as well as hardness test indicate that the mechanical and microstructure properties of FSS exhibit a substantial change after welding. The major effect observed on the low-angle grain boundary increases as a result of fine-grained equiaxed ferrite [7]. Salemi Golezani et. al.[8] used a heavy-duty NC machine to perform FSW for joining FSS grade A430 sheets with thickness measures of 2 mm. They studied the impact of traverse and rotating speed of tungsten carbide tools on mechanical and microstructural properties. The use of a brass chamber assisted with water cooling avoids the wear and damage of the tool. In addition, protection applied with argon gas provides shielding to counter tool oxidation at elevated temperatures. Varying rotational speed and welding speeds were selected. Results disclosed that increasing the welding speed at constant rotational speed decreases ferrite grain size, which verifies active recrystallization existence in the nugget zone. Mehmet Burak Bilgin et.al.[9] analyzed the effects of the various speed of FSW tools including traverse and rotational speed of ferritic stainless steel grade 430. Two samples of grade A430 of the same thickness as 3 mm were butt welded with friction stir welding. It was detected that the greatest values of mechanical properties were attained at a tool traverse speed of 125 mm/min and rotational speed of 1120 /min. While the tool angle should be kept as 0^0 and a continual pressure force of 3.5 kN needs to be applied. The rapid cooling done on FSS after its friction stir welding transforms the ferrite grains from coarse to the fine structure since rapid cooling in addition to frictional stirring initiates severe plastic deformation which further develops a high strain. The fine grains allow the joint to exhibit good impact strength/toughness and ductility as well [10,11].

Laser beam welding (LBW) is also a useful technique to join FSS sheets and to prepare similar/dissimilar joints. With the increase in welding speed, the heat-affected zone (HAZ) becomes narrower and simultaneously the hardness moves up on the higher side. The varying welding speed does not produce any major change in tensile strength, but at a higher welding speed, greater elongation is achieved [12,13]. The test results show that the rapid solidification of laser beam welded FSS joints of grade 409M, reflects excellent bending strength and toughness due to the formation of dendritic grains from the coarse ferrite grains of base metal [14-16].

Once comparing the tensile strength of two different ferritic stainless steel grades i.e. 444 and 429L, butt welded with the help of gas metal arc welding (GMAW), it has been found that 429L has more tensile strength [17]. Tapan Kumar Pal et.al.[18] experimentally investigated the process response and the microstructure of dissimilar joints made of low Ni ASS grade and 409M FSS grade. Elemental mapping indicated that the material flow strategy during FSW relies upon the blend of the adopted procedure parameters. Dynamic recrystallization and recuperation are additionally seen in particular dissimilar joints. The FSS displays increasingly serious powerful recrystallization, bringing about an extremely fine microstructure, likely because of the higher stacking energy among the two distinctive grades of steel selected in the present investigation. Gas tungsten arc welding is a versatile process that is frequently used for industrial purposes [18,19]. The FSS grades can also be easily welded by GTAW/TIG and demonstrate better weldability aspects, while the precipitation of carbide and martensite formation is the major issue experienced with this welding technique. These issues should be controlled to hinder unaccepted grain growth in HAZ. It has been found that the intensity of the heat input selected during this welding technique leaves a great effect on grain growth [20,21]. Narrow HAZ, an increase in microhardness and grain refinement with additional equiaxed crystals can be achieved by adding nitrogen gas in argon-based shielding gas provided with a double layer shielding since nitrogen gets dissolved into the weld pool. Due to microstructure refinement takes the toughness of the welded FSS joint also increases significantly. It has also been observed that the ductile fracture region normally developed very near the surface of the weld [22,23]. The pulse mode used for metal transfer enhances the mechanical resistance and metallurgical properties of FSS (grade 409M). This could be attained as this metal transfer mode expressively modifies the composition of the weld metal as compared to spray mode. In spray mode of metal transfer, the stability of the austenite phase gets promoted and at variable heat inputs, the grain structure features considerable enhancement. Pulse mode upgrades hardness as well as impact toughness of weld metal as compared to spray mode at any given heat input [24].

The relationship derived for the resistance spot welding process and microstructure changes on ferritic stainless-steel grade 430 show that numerous parameters like the formation of martensite, carbide precipitates at the grain boundary, and grain growth significantly affect the microstructure of heat affected zone (HAZ) and fusion zone (FZ). It is worth noted that due to the above facts there is an adverse effect on mechanical properties [25-28]. WenyongWu et.al [29] investigated the microstructure of FSS joints (similar/dissimilar) using SEM, XRD, and optical microscopy methods and found that in dissimilar joint (when FSS welded with low carbon steel) widmanstatten ferrite is formed very near to HAZ. With an increase in welding speed, the hardness of the welded zone is improved and at the same time, the HAZ becomes narrower. Varying welding speed does not have any effect on the ultimate strength of the joint but an improved elongation is attained at a higher speed. The test result of corrosion analysis reveals that dissimilar joint possesses better corrosion resistance which is mainly due to the presence of galvanic corrosion. FSS with low Ni percentage displays good strength and better stress corrosion resistance in various corrosive environments [30]. Experimental results show that HAZ of FSS grade 444 welded with electrode E309MoL-16 (AWS) exhibits considerable grain growth as compared to the base metal. Very fine precipitates needle-shaped were detected in the partly molten zone which can be judged as Laves phase. In addition, finely dispersed precipitates were also observed in HAZ and this is due to the weld thermal cycle. The X-ray diffraction (XRD) study established the availability of a few carbonitrides and chromium nitrides as well as certain secondary phases like chi and sigma [31].

2.2 Corrosion

J.H. Potgieter et.al.[32] deliberated the pitting corrosion behavior of FSS grade 444 with the help of electrochemical methods comprising cyclic potentiodynamic polarization, chronoamperometry, and immersion tests besides test to identify corrosion extents. An attempt was made to observe preceding and succeeding corrosion tests, utilizing the scanning electron microscopy (SEM) technique which displays indistinguishable corrosion behavior in all the corroded environments (solutions) subjected to allow the samples for only one minute into the solutions. It is also to be noted that 444 shows improved corrosion confrontation in chloride environments. While sulphuric acid it has additional corrosion pits. P. D. Antunes et.al.[33] analyzed the effect of weld metal interaction on the predisposition of 444 FSS weldment to SCC in hot chloride, by continuous load tests and metallographic investigation. To develop weld joints with unlike chemical configurations in fusion zones, two different filler metals E316L and E309L (both are from the austenitic stainless steel domain) were used. The SCC test outcomes revealed the susceptibility of the interface among the FZ and the HAZ. The investigation carried out to find the effect of chloride impurity level and the corrosion mechanism on the susceptibility of FSS and ASS suggests that FSS experiences a substantial mass gain due to the formation of a thick as well as non-protective oxide scale. Furthermore, ASS shows greater resistance to corrosion in high and low chloride salts [34].

2.3 Pre weld heat treatment

The analysis was done to examine the effect of annealing on corrosion behavior of FSS and found that annealing may not be able to improve the resistance against crevice corrosion and pitting but it does advance the weldability of the material by hindering carbide precipitations [35].

The surface grinding operations are done on FSS to improve the corrosion resistance of the material. These operations hinder the corrosion process at grain boundaries which are located just under the surface layer and also discourage the progression of microcracks when the material is exposed to high loads [36].

3. Discussion

The corrosion-resistant and high-quality materials costs are growing day by day and with this fact, ferritic steel is a decent option for the utilization in the chloride condition and numerous uranium improvement plants. In these applications welding is the primary procedure for the development of designing structures that debase their properties. In this way, unique consideration is required for the improvement of mechanical properties of FSS during welding which has still a few issues. The use of numerous arc welding processes (like TIG, GMAW, SAW, SMAW, etc.) responds to the formation of undesirable precipitates, grain morphologies, and the development of residual stresses. While it is shown in earlier works that low-energy welding processes can be preferred but with these, there is an issue of incomplete penetration. In terms of grain refining, intergranular oxidation, and fragility, numerous studies have been conducted on the welding of FSS. Because of these variations, the microstructure and mechanical properties are greatly affected.

Friction stir welding is recommended to be used as a joining technique of various grades of FSS with the thickness of these plates/ sheets to be on the lower side. The process parameters should be accurately selected and monitored during the welding. The rapid cooling renovates the ferrite grains from coarse to fine structure. During the FSW process, argon gas shielding helps to counter tool oxidation at elevated temperatures. In addition, the use of a brass chamber assisted with water cooling avoids the wear and damage of the tool. The literature also illustrates that while performing Laser beam welding (LBW) to join FSS sheets/plates the welding speed should be kept at moderate since it narrows the HAZ is also a useful technique to join FSS sheets and to prepare similar/dissimilar joints. With the increase in welding speed, the heat-affected zone (HAZ) becomes narrower and simultaneously the hardness moves up on the higher side. The research work which is done so far on the corrosion behavior of FSS demonstrates that this steel encompasses better corrosion resistance as compared to most of the current ASS grades.

4. Conclusion

An attempt has been made to identify welding processes which are suited for joining FSS and to study the corrosion behavior of these stainless steel grades in the various corrosive environment. While using FSW it is recommended to select appropriate (higher side) plunging depth, as it decreases the grain size and thus improves hardness. Post welding the mechanical and microstructure properties of FSS exhibit a substantial change. Fine-grained equiaxed ferrite contributed to increasing the low-angle grain boundary. The use of an appropriate shielding method (argon gas shielding) helps in getting better weld beads even at higher temperatures.

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