A Review on Welding Characteristics of Ferritic Stainless Steels and Effects of Various Weld Process Parameters

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Abstract

Today is the world of stiff and cut-throat competitiveness among the manufacturing industries. The objective of every industry is to produce better quality products at minimum cost and increase productivity. Welding is a process where the coalescence of two metals is achieved by the application of heat and/or pressure with or without filler metal. This is the only technique for developing the monolithic structure. Welding defects can cause practical problems if not solved. The TIG welding is also called Gas Tungsten Arc Welding (GTAW), which uses a non-consumable tungsten electrode to produce the weld. TIG welding is used to produce high-quality welds and is popular among welding processes. Its productivity depends upon many factors like arc voltage, shielding gas, weld speed, and heat generated during the welding process. This paper is an attempt to present a review about the welding of ferritic stainless steel between AISI 410S and AISI 430 by the TIG welding process.

Keywords: Filler metal, TIG welding, GTAW, Shielding gas.

Introduction

Stainless steel is mainly made of iron and carbon. The addition of chromium (Cr) and other alloying elements such as nickel (Ni) provides a high degree of corrosion resistance that makes stainless steel different. A chromium oxide film is formed when chromium is added to steel and acts as a protective layer to prevent air and moisture from causing rust. Hence it is used extensively. Stainless steel has a carbon percentage of 0.03% to 1.2%. Stainless steel contains about 10.5 to 30% of Chromium, depending upon the application. Silicon, Nitrogen, and Manganese are other alloying elements that are added to steel to meet the specific end-use application. The major reason why stainless steel is used is because of its shear strength.[1] For example - the automotive industry, home appliances, medical equipment manufacturing, architecture and construction, and many more. Ferritic stainless steels have only one alloying element as chromium which ranges from 10% to 30%. These are non-hardenable by heat treatment, and only marginally hardenable by the cold rolling process. These are excellent corrosion resistant. The BCC grain structure is responsible for ferritic steel's magnetic nature. Ferritic stainless steel mainly consists of 400-grade series. Some applications of ferritic stainless steels are heat exchangers, petrochemical, automotive exhaust systems and trim, home appliances, and food catering equipment. AISI 430 is the most widely used grade of ferritic stainless steel. AISI 439 has greater corrosion resistance, AISI 409 has a lower chromium content. The martensitic steels contain 11.5% to 18% of chromium and up to 1.2% carbon. They are less corrosive resistant than ferritic stainless steels. These steels have extremely high strength, low fracture resistance, and low ductility. The hospital equipment, scissors, screwdrivers, staple guns, etc are some applications of martensitic steels. The austenitic stainless steels contain at least 15% of Cr. They also contain 2% to 20% nickel which enhances surface quality, formability, corrosion, and wears resistance. The austenitic steels are non-magnetic in the annealed condition. They are excellent corrosion resistant, as a result often used for stainless steel applications. AISI 304 is the most widely used. Some applications of austenitic steels are industrial use, architectural products, transport, etc.

2. Literature Review

Stainless steel has a destructive resistance due to chromium pressure in combination with oxygen. Now with a little bell! Chromium is a compound that promotes the formation of ferrite in iron; in the case of ferrite metals, this ferrite is a high-temperature form known as delta-ferrite. Unlike low-alloy steels, therefore, this type of steel has no phase changes as it cools from melting to room temperature; therefore they are not able to withstand heat treatment and this has an impact on the properties of the joints. Ferrite wireless metals are usually installed in small sections. Most are less than 6mm thick where weight loss is less important. Most conventional arc welding systems are used although it is considered the practice to limit heat intake with these metals to reduce grain growth (temperature of 1kj / mm and high temperatures of up to 100-120 ° C is recommended) which means that high-level investment processes are not recommended. In the manufacture of machinery made of stainless steel such as a pipe. Gas system for exhaust car, chemicals, etc.[2]

Ferrite stainless steel is known for its excellent resistance. Against cracking resistance to oxidation at high temperatures, hole penetration, and environmental corrosion in the chloride area. In the case of chloride, the nature of ferrite metal to be much better than most austenitic grade father stainless steel is needed to find better ways to join these materials either the same or different metal. Joining different instruments is often a bigger challenge than similar instruments that often occur due to several factors such as differences in chemical composition and thermal enhancement chemicals. The most common TIG welding continues as one of the largest welding processes used in the industry by high-quality members and an effective way to join two or more instruments permanently and make them work as a single piece. In this welding process in which an electric arc forms between a non-corrosive wire electrode and a work wire heating steel or leads electrode is applied to all industrial structures but is most suitable for high-quality heat. In this particular study, testing is performed by maintaining oxidation or other atmospheric pollution by adding a protective gas (argon or helium) regularly and flexible welding process It is an automatic arc-based process because the molten metal feed wire is used to assemble metal plates. The same and different pieces of metal are assembled using TIG welding to determine the impact [3-4]. During welding, the gases cannot escape from the molten lake and severely damage the mechanical properties, causing loss of mechanical strength and mobility, fatigue, and rust failure, etc.

Welding was performed on Stainless steel with 409 grade. It was found that tensile strength and yield strength of weld material got reduced by the base metal strength by 40 to 42%. GMAW and GTAW processes have higher yield and tensile strength because in these ductility is more. GTAW welded material has higher toughness while GMAW and SMAW have lower hardness values.[1] Fusion welding to weld the material. The tensile strength of the material decreases as compared to the base material. The study on ferrite stainless steel shows the effect of spot welding. A heat treatment technique is applied on standard duplex stainless steel welds to investigate the influence of thermal treatment. A groove of 30*10*30mm duplex stainless steel was performed using flex curved are welding. after welding, another groove 12*8mm was mild in the center and after wielding the result that is come is the temperature is uniformly distributed among the fusion boundary, and coming to microstructure results there are 55% of ferrite fraction and 45% of austenite.[2] In another process, bi-metal weld novel 400 tubes were welded with stainless steel 316 tube by GTAW process. After the welding heat treatment process was performed the physical and mechanical properties changed without a change in the material shape and it was found that novel 400 has a lower corrosion rate.[3]

The study of activating flux mechanisms by increasing weld penetration has great significance in developing flux and welding processes. Since the shallow depth of penetration is low, the productivity achieved by the TIG welding process is also low. Experiments were performed with ferritic stainless steel of grade 430. The specimen had a dimension of (200 mm × 200 mm × 5.5 mm). The product was further heated at 150°C. During the testing of mechanical properties, tensile test, it was found that the UTS of ATIG welding was greater than that of TIG welding. In the hardness test, it was found that ATIG welding is greater than TIG welding. Corrosive resistance was found more in ATIG welding than TIG welding.[4] Activating flux tungsten inert gas (ATIG) and Multiphase tungsten inert gas (MTIG) welding process was performed on an 8mm thick 409 ferritic stainless steel. While SiO_2 oxide was used as an activating flux in ATIG welding, SUPER TIG ER309L was used as a filler material in the case of MTIG welding. Hardness, tensile test, and Charpy toughness test were evaluated. Results indicated that the TIG process had more penetration power and greater strength compared to the MTIG welding process.[5] In the Laser welding experiment, argon gas was used as a shielding gas with 2000 W of constant welding power. Welding speeds were 100, 200, 300 cm/min. The tensile strength of the welded joints was measured and found to be greater. The results of all the tests and measurements were obtained and it indicated that the best properties were observed in the specimen and welded joints when welded at 100 cm/min welding speed.[6]

To investigate the effect of heat input on microstructure and mechanical properties of ferritic stainless steel of grade 409L GMAW process was performed. ER304L and ER308L were used as filler materials. Heat input of 0.3, 0.4, and 0.5 kg mm^{-1} were used. Between the heat input range of 0.4 to 0.5 Kg mm^{-1}, the welded sample was found to be more superior in exhibiting mechanical properties. The mechanical properties of using ER304L filler wire were better than that of ER308L filler wire.[7] Friction stir welding was performed on 4 mm thick plates of AISI 410S ferritic stainless steel. The welding performs at a different condition. The first condition is at 450 rpm with axial force 22KN and at 800rpm with axial force 20KN. So at first heat generation is less and at second condition heat generation is more because, mainly due to the greater contact of the material with the tool shoulder. After that, they perform a DL-EPR test on the material it is an efficient technique to analyze the susceptibility of stainless steels to intergranular corrosion after they have been subjected to different types of processing such as heat treatment and welding processes. DL-EPR test also shows whether after welding there occurs microstructural changes capable to make some areas of weld susceptible to corrosion.[8] TIG welding is also useful for the joining of metals. A specimen of 50*50*3 dimensions was welded in the butt joint. Then tungsten arc welding is used with direct current electrode negative (DCEN) by using an argon gas shield. Three pairs of specimens were weld with three pairs of SS310 plates for microstructure observation the specimen was cut into 10mm width and etched with picric acid. Results exhibited that the weld had a greater hardness value.[9]

The material used in this investigation 444 stainless steel approximately 2 mm thickness. Then they perform gas tungsten arc welding on the material without using filler metal. After that selected welds were annealed in a vacuum furnace at 980 degrees and air-cooled. Welds were polished both mechanically and electrolytically. Then fracture surfaces were observed in an electron scanning microscope. Most of the striking differences in the features of weld metals and the base metals apart from grain size were distribution and size of the TiN or Nb (C, N) particles found.[10] Friction stir welding is another technique to join the stainless steels. The metal flow in FSW is composed of two modes of transfer, occurring due to either extrusion of metal around the tool probe or the friction heat generated between the tool shoulder and sample. Defects are eliminated by frictional contact between tool and workpiece such as axial force and rotation speed. A decrease in speed decreases heat generation. Similarly, as axial force decreases, the heat generation also decreases.[11]

In this experiment, material AISI 410S ferritic stainless steel is cut in the dimension (90*180*0.6mm) by using a laser cutting machine. After that, the material is joined by using plasma arc welding with a variety of welding currents. After welding their occurs changes in the property of the material as compared to the base materials. The first change occurs in mechanical property. They perform a tensile test on the materials the tensile strength of the material is lower as compared to the base materials. The main reason is that for having lower mechanical property is microstructural transformations. Ductility and grain coarsening were increase. [12] The friction stir welding process performed on AISI 430 concluded that the hardness of the material increases because of grain refinement and the formation of the martensite phase in the stir zone. Additionally, the corrosion current density of the FS processed specimen was found to be higher than that of base metal. In the microstructure of ferritic stainless, there is no dislocation occurs.[13]

The experiment performs on ferritic and austenite stainless steel plates of 5.7 and 4.6 mm of thickness they were welded together by Robotic GMAW process. The microstructure of welded material is austenite side result smaller than the ferritic side. The austenite side gets affected by the welding process. And the microhardness in HAZ of ferritic stainless steel was relatively elevated, nearly 350 Hv compared with 230 Hv in the HAZ austenite steel.[14] Another GTAW process was performed using ferritic steel. The welding was carried out under different heat inputs. As heat input increases it enhances the area of the material; due to this change occurs in the microstructure property of the material. This enhances the delta ferrite in the matrix due to the higher solidification rate. As delta ferrite increases the toughness of the material is enhanced.[15]

In this experiment, the base material AISI 410S super martensitic stainless steel cut into dimension (100*50*6mm). after this TIG welding is carried out on these plates. Metallurgical studies say that penetration is increasing in the direction of fluid flow. And the microstructure of the welding material fine base compares to the base material. TOPSIS is suggested for optimization of welding parameters in TIG welding of SMSS. After that hardness test is performed on the welded material and the hardness of welded material is lower than the hardness of the base material because of grain size.[16] SMAW welding of AISI 410S ferritic stainless steel with the AWS E309MoL austenitic stainless steel shows the variations in the composition of the weld metal due to dilution being dissimilar welding. The use of petroleum in this experiment is highly corrosive. The microstructure had little influence on the material's corrosion due to a change in heat input.[17]

This study investigates the influence of the Nd–YAG laser power wave mode on the porosity and mechanical properties of SUS 304L and Inconel 690 Elements. Initially, a rectangular laser power waveform is specified. Austenitic stainless steels and nickel-based alloys are generally welded using conventional shielded material arc welding, gas tungsten arc welding, or gas arc welding processes. welding was performed using a Rofin-Sinar on the material at 1050˚C for 5min and then quenched in water. Butt welding tensile strength of Inconel 690 increases the rupture position, and the tensile strength and percentage elongation increases. For both materials, the porosity ratio formation ratio of butt-welded specimens. Decreases as the level of longitudinal ratio increases. It is assumed the porosity reduction effect of the laser pulse is more significant in Inconel 690 than in SUS304 Land the tensile strength of Inconel 690 increases significantly as the level of longitudinal ratio increases.[18]

Three-dimensional temperature and plastic flow fields during friction stir welding of 304 austenitic stainless steel have been calculated by solving the equations of conservation of mass, momentum, and energy and the temperature and material properties. Temperature-dependent thermal conductivity, specific heat, and yield strength were considered. Results show that significant plastic flow occurs near the tool, where convective heat transfer is the main mechanism of heat transfer[19]. In this paper during fusion, the presence of sulfur in the metal often affects the temperature and flow of the liquid in the weld pool and its geometry. Here we report experimental and modeling investigations of tungsten arc butt welding gas for stainless steel plates containing various sulfur compounds. Even though sulfur congestion of the welding pool is affected by weld geometry, a Flaring arc facing the low sulfur side was found. The main variables studied were sulfur concentrations in the two plates, welding current, and welding speed. The results show a significant shift of the fusion zone toward the low sulfur steel.[20].

AISI 316L and AISI 430 stainless steel were assembled to evaluate metallurgical and weldability properties by using pulsing current gas tungsten arc welding (PCGTAW) process with the help of ERNiCr-3 and ER2209 filler wires. The grain coarsening effect was observed during the welding process because of the presence of Nb in the filler. During the use of EE2209 filler, segregation was vividly found, the presence of cellular, columnar and dendritic growth was also observed. It was found that the welding of the two plates was free from macroscopic defects.[21] Four different grades of steel were used; 1.4016 (AISI 430) and 1.4003 (low-carbon ferritic) type steels in the ferritic steels group and 1.4162 (low-alloyed duplex, LDX2101) and 1.4462 (AISI 2205) type steels which comes in the duplex steels group to determine microstructural changes. The fiber laser and gas tungsten arc welding was used to vary the cooling rate of the weld parts to produce better results. The results showed that the microstructure of ferritic stainless grade 1.4003 was fully martensitic in all welding parameter combinations used. The hardness of the martensite structure obtained was dependent on heat input, increasing heat input decreases the hardness. The formation of martensite and grain size of ferritic stainless steel 1.4016 was similar. When there was low heat input no martensite was obtained, but the grain size obtained was high and vice-versa.[22]

A flat butt weld was welded with ferritic stainless steel of grade 430 (X_6Cr_{17}). In the case of TIG welding, the weld pool is more shallow so the TIG arc can heat the weld pool to the maximum temperature. Whereas in ATIG welding the weld pool is deeper and the volume of molten metal is larger. During the microstructure analysis martensite, and austenite formation was seen. The average grain size in the HAZ was in the range of 60-120μm. When heat input was reduced the grain size of both the weld joints decreased. The results concluded that the higher the heat input higher the formation of martensite and austenite. In the case of ATIG welding, less grain coarsening and martensite was present immensely. The formation of martensite increases as faster cooling takes place [23]. GMAW welding process of 409M was performed to study the metallographic analysis. Pure Ar, Ar+5%CO_2, Ar+10%CO_2, and Ar+20%CO_2 were used as shielding gas mixtures at constant heat input. Two specimens were prepared; one unnotched smooth transverse specimen for evaluating transverse tensile test and one notched specimen for evaluating notched tensile properties. All of the tensile tests were conducted with 100 kN using the electromechanical controlled universal testing machine. The grain size was measured using the linear intercept method from the optical micrographs with a help of software called AXIOM.[24] Using autogenous arc welding processes tensile test, fatigue test, hardness test were analyzed. The tensile test was conducted with 100 KN of force. The hardness of the weld was measured with a 0.5 kg load. Fatigue crack growth experiment was conducted with a help of servo-hydraulic, and with a 100KN universal testing machine. The joint fabricated by the PAW process had higher strength than that of the PCGTAW and CCGTAW joint. Additionally, the Charpy impact toughness test was also conducted. Of the three the joint fabricated with PAW exhibited higher toughness. The microstructure test concluded that the fusion zone (FZ) contained ferritic grains. The fatigue crack growth test was conducted at different stress levels (Δσ) of 75, 100, 125, 150 and175MPa. The fatigue performance of the PAW process was greater than the other two.[25]

3. Discussion

The stiff and cut-throat competitiveness among the manufacturing industries has increased the objective of every industry to produce better quality products at minimum cost and increase productivity. Stainless steels being excellent corrosive resistant finds their use in a variety of applications. Numerous arc welding processes like TIG, ATIG, GMAW, SAW, SMAW, laser arc welding exhibits different characteristics. Due to heat input variations, oxidation, formation of HAZ, weldability, and other factors the microstructure and mechanical properties are greatly affected in Ferritic stainless steels. The formation of martensite increases as faster cooling takes place in the case of ATIG welding. The use of activating flux mechanism can increase the weld penetration which has great significance in developing flux and welding processes. Friction stir welding is another technique to join the stainless steels. Friction stir welding is another welding process of joining the metals. The metal flow in FSW is composed of two modes of transfer, occurring due to either extrusion of metal around the tool probe or the friction heat generated between the tool shoulder and sample. The process parameters have to be accurately selected and monitored during the welding. HAZ varies from small to large depending upon the rate of heat input. Welding operations with high heat input rate have faster cooler rates, while welding operations with low heat input rate has low cooling rate. The FSS experiments demonstrate that they are highly corrosive resistant, and have greater strength.

Conclusion

The joints were fabricated by using tungsten inert gas welding (TIG) on ferritic stainless steel (FSS) to know the behavior of the material like mechanical property and also corrosion behavior of ferritic stainless steel in a different environmental condition. The grain size influences the hardness of the material. Welding exhibit that there occur some significant changes in their mechanical and microstructure property of the ferritic stainless steel. The welding process is carried out under appropriate shielding conditions. The use of the conventional GTAW process is one of the most significant advancements for overcoming the shortcomings of TIG welding, which helps in increasing the penetration depth and depth to width ratio of the weld pool, which increases the productivity of the process and helps in achieving better mechanical properties.

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