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An Overview of Welded Low Nickel Chrome-Manganese Austenitic and Ferritic Stainless Steel

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Abstract

Welding of Low Nickel Chrome-manganese Austenitic and ferritic Stainless Steel is an emerging area of research. Due to nickel price volatility, there was been increased interest in no-nickel or low-nickel economical grades of stainless steel. Chrome -manganese austenitic ("standard 200-series") and ferritic stainless steel ("standard 300-series") grades with well-defined technical properties have proved acceptable materials for specific applications for many years. This increase in the use and production of these low nickel grades is not currently matched by a proper level of user knowledge. So there is a risk that they may be used in unsuitable applications. It is very important to cultivate the method of fabrication like welding. This paper looks at the behavior of low nickel chrome-manganese and Ferritic austenitic stainless steel in terms of microstructure and sensitization effects.

Keywords: AISI 200 SS; AISI 400 SS; Intergranular corrosion (IGC)

Introduction

In the late 1980s, a nickel crisis caused the Indian government to reduce nickel imports [1]. This led to development and production of the chrome manganese and ferritic stainless steel grades in that country. Due to increased knowledge of these grades consequently began to be acquired and many high suitable applications for the grades emerged. As a result there has been increased interest in economical low-nickel grades of stainless steel having properties similar to AISI-300 series stainless steel. The AISI-200 series and AISI-400 series grades of stainless steel is a well-known example of low-Ni stainless steel.

Low nickel Chrome-manganese grades were first developed in the early 1930s [2]. As a way of conserving available nickel, which led to use of chrome-manganese grades increased during the 1950s in America and new grades with higher properties have continued to be developed [1]. Rises in the material's popularity have been linked to highly increased nickel prices and advances in steel production technology. This leads to higher use of AISI 200 series, alloyed with manganese (Mn) and the other alloying elements like nitrogen (N) and copper (Cu). Manganese acts as a substitute of nickel, in order to stabilize austenite phase [1,3]. These low-nickel stainless steels are economical than 300-series and are popularly known as chrome-manganese stainless steel [4]. Its current contribution in total stainless steel production is more than 10% [5,6]. In future 200 series alloys will have greater demand and will acts as replacement over 300 series for variety of industrial applications [6,7]. Low nickel Cr-Mn SSs are used in various applications like home accessories, home appliances, light poles, construction, outdoor installation etc. where high corrosion resistance is not required [1,8,9]. In some applications welding of the materials is important. Ferritic stainless steel are BCC crystal structure with iron-chromium alloys containing 12% to 30% of chromium with a carbon content below 0.10% along with other alloying elements, notably molybdenum having similar properties to those of mild steel but show better corrosion resistance [3,10,11]. FSS are noted for their excellent resistance towards stress corrosion cracking and good resistance to pitting and crevice corrosion in chloride environments [12], due to their lower cost of production and good resistance to corrosion, as compared with austenitic stainless steels it becomes second most widely used type of stainless steel [13]. As FSS is heated above a critical temperature, austenitic structure is obtained and partially transform into martensite on cooling but not enough to impart high strength [12].These steel exhibit good formability, ductility, and moderately better yield strength to those of the austenitic grade, but the high temperature strength of FSS is somewhat poor. Most commonly used ferritic stainless steel grades are 12% and 17% chromium-containing grades, which are used mostly in vehicle exhaust systems and the latter mostly in washing machines, cooking utensils, and indoor architecture. Due to its magnetic property, these steels can be easily distinguished from austenitic stainless steels grades.

Welding is one of the most economical and widely used processes to fabricate stainless steel structures [2]. The welding processes have been used in different applications such as chemical industrial equipment repairs, pipelines, automotive exhaust gas systems. However, welding has powerful effects on the microstructure and hence is expected to have strong influence on the corrosion and mechanical properties of the welded samples. Some of the problems associated with welding in the austenitic stainless steels are sensitization of the weld heat affected zone, hot cracking of weld metal and decrease in corrosion resistance. This article provides a review of the various research activities carried out on Welded Low Nickel Chrome-manganese Austenitic and ferritic Stainless Steel.

Process Parameters

Welding technology has the widespread applications but needs constant upgrading. Experienced welding personnel are needed to consistently produce high quality of welds. Welding parameters should be selected properly for a given task to provide a better weld quality which identified by its micro-structure and correct weld bead shape, and relied on the amount of spatter. Investigation into the relationship between the weld bead shape and welding process parameters began in

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the mid1900s. Nearly 90% of welding in world is carried out by one or the other arc welding process; therefore it is imperative to discuss the effects of welding parameters on the weldability of the materials during the arc welding.

Welding current

Y.D.Han studied the influence of welding parameters in shielded metal arc welding (SMAW) process and studied that welding current (I) is the most influential parameter because it affects the current density and hence the rate of filler and base material [1,13,14]. This welding current influences on mechanical and microstructural properties by altering its weld pool and heat affected zone (HAZ) width. Penetration and reinforcement increase with the increase in welding current. If the current is too high at a given welding speed, the depth of penetration will also be too high so that the weld may melt. Undercut and Digging arc are produced due to high current also leads to waste of electrodes in the form of excessive reinforcement. This overwelding increases the weld shrinkage and led towards the greater distortion. As welding current increases, weld bead shape increases until a critical value is reached and then starts decreasing by using polarity DCEP. But when DCEN polarity is used weld bead shape increases with the increase in current for entire range [15]. Heat affected zone also increases with the increase in welding current if same flux is used. Too low current may lead to inadequate penetration and incomplete fusion may result. Too low current also leads to overlapping, inadequate penetration and unstable arc.

Welding speed

Welding speed is the linear rate at which an arc is moved along the weld joint. With any combination of welding current and welding voltage, the effect of changing the welding speed confirms to a general pattern. If the welding speed is increased, heat input per unit length of weld is decreased and less filler metal is required per unit length of the weld, resulting in less weld reinforcement. Thus, the weld bead becomes smaller. Welding speed is the most affecting parameter for weld penetration other than current. This is true except for excessively slow speeds when the molten weld pool is beneath the welding electrode. Then the penetrating force of the arc is cushioned by the molten pool. Excessive speed may cause uneven bead shape, porosity, undercutting, cracking, arc blow and higher slag inclusion in the weld metal. Aksoy observed that higher welding speed results in less heat affected zone and finer grains [16]. Within limits, welding speed can be adjusted to control weld size and penetration. Relatively slow welding speed provides time for gases to escape from the molten metal as a result reduction in porosity. An excessive slow welding speed produces a rounded weld bead shape which is subject to cracking and higher arc exposure which is uncomfortable for the operator. Too large molten pool may also result due to low welding speed that flows around the arc and led to burn, rough bead and slag inclusions. It was also reported that the welding speed did not affect the metal deposition rate significantly.

Electrode size

Electrode size affects the depth of penetration and weld bead shape and at fixed current. Electrode size mainly influences the deposition rate. At any given current, a small diameter electrode will have a higher deposition rate and higher current density than a larger electrode. However, a large diameter electrode will carry more current than a small electrode, and produce a higher deposition rate at higher amperage. For the same values of current, arc voltage and welding speed, an increase in electrode diameter results in a slight increase in the weld bead shape [17].

Research in Filler Material Used

Filler rod selection is very important to achieve a weld metal with the proper strength characteristics and desired corrosion-resistant [12]. Due to long list of stainless steel filler metals which frequently causes concern as to how to select the filler metal appropriate for a given application. Selection of the correct alloy composition, however, is generally the same as for SMAW in that the filler metal should match the base metal. Introduction of any contaminants into the weld zone can be prevented by proper cleaning of the filler rods. Usually, filler rod is over alloyed with 2-4% Ni greater than the base metal content [12].

Shanmugam [18] studied effect of filler metals such as ferritic stainless steel, austenitic stainless steel, and duplex stainless steel on fatigue crack growth behaviour of the gas tungsten arc welded ferritic stainless steel joints. The results of investigation show that the joint fabricated by austenitic stainless steel filler metal rod primarily contains solidified dendritic structure of austenite and the joint fabricated by ferritic stainless steel filler metal rod contains solidified ferritic grain structure. But, the joint fabricated by duplex stainless steel filler metal rod primarily contains solidified austenitic structure in the ferrite matrix .Of the three joints, duplex stainless steel joint offered higher fatigue resistance than ferritic stainless steel and austenitic stainless steel. From the above experimental results, it is understood that the fatigue crack propagation behaviour, fatigue life and fatigue crack initiation behaviour of ferritic stainless steel joints are very much depends on the filler metals used.

Wichan and Loeshpahn [19] studied the effect of filler metal rod on microstructure, corrosion and mechanical behavior of dissimilar weldment between and low carbon steel sheets and AISI 201 stainless steel produced by gas tungsten arc welding (GTAW). It was concluded that the ER316L and ER309L fillers are the good candidates to promote the pitting corrosion resistance of weld metals and were comparable with that of AISI 201 base metal. This effect on is due to the high Mo content (2 wt %) and Cr content (21.347 wt.%) in ER316L filler metal , the Cr content (24.791 wt.%) in AISI 309L filler metal.

Research in Shielding Gas Used

The main function of the shielding gas is to protect the weld pool from contamination from air, which may led to defects and porosity in the weld [20]. Material to be welded decides the composition of a shielding gas mixture for the given welding. The selection of the shielding gas should be done by all means, taking into account metallurgical- chemical processes between the molten pool and the gases that occur during welding process. The shielding gas is a very important pathway for the welding arc, which will help in the proper starting and running of the welding arc. There are many shielding gases available but helium and argon are most common and widely used in Industries for the welding process.

Each of these two gases has advantages.

Helium

1) Higher arc voltages

2) Better penetration

3) Faster travel

Argon

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1) Low gas flows needed

2) Good cleaning action

3) Better arc starting

4) Lower arc voltage

Because of the cost of Helium we are now seeing mixtures of Argon and Helium. This is to gain the best part of each gas. Somrerk [21] carried out the plasma arc welding between AISI 201 and AISI 304 stainless steels. It was found that mixing nitrogen in shielding gas argon up to 12% (v/v) could reduce the amount of delta ferrite in austenite matrix from 20 to 16%, v/v. It also increased pitting corrosion potential from 401 mV to 472 mV as compared to Ag/AgCl. This was due to the increased nitrogen content in the weld metal which was from nitrogen in shielding gas.

Ahmet's [20] experiment on the effect of hydrogen in argon as a shielding gas in tungsten inert gas welding (TIG) of austenitic stainless steel showed mean grain size in the weld metal, which increased with increasing hydrogen content and finally led to increase in the weld metal penetration width and its depth. Shanping [22] reported in their paper that small addition of oxygen content to the Helium-Argon mixed shielding could significantly change the weld shape from a wide shallow type to a narrow deep one.

Welding Effect of Chrome-Manganese Grade SS

Microstructure

Wichan and Loeshpahn [23] studied the effect of welding speed on microstructures of GTA-welded AISI 201 stainless steel .It was observed that the austenite grains with twins were as a typical microstructure of stainless steel. As a welding speed increases, the inter-dendritic spacing in the weld metal is reduced with dendrite size and, supported these results by Nowacki and Rybicki [24], Kumar and Shahi [25], and Shyu [26]. The microstructure of the austenitic stainless steel AISI 201 base metal is shown in Figure 1. Optical micrographs showing the microstructures of HAZ, fusion boundary and weld zone are presented in Figure 2. This variation in the dendrite size can be attributed to the fact that at low heat input due to high welding speed, cooling rate is relatively high which lead to steep thermal gradients in the weld metal which gives lesser time for growth of the dendrites, whereas at high heat input due to low welding speed causes slower cooling rate which provides sufficient time for growth of the dendrites into the fusion zone [25,27].

Himanshu Vashishtha [7] studied Welding Behaviour of Low Nickel Chrome-Manganese Stainless Steel. It was observed that width of heat affected zone increases with increase in heat inputs. Accordingly considerable alterations in grain size (grain coarsening) were found and cause HAZ growth. Maximum tensile strength possessed by low heat input welded joint due to smaller dendrites and low spacing. Typically the dendrites decided the mechanical properties of welded joint. In the area of weld zone, only dendrites structure is present. We know that as the heat input value increases, the cooling rate decreases respectively. It has been observed that higher the cooling rate, shorter the solidification time and finer the dendrites structure as shown in Figure 3.

Sensitization

When the austenitic stainless steel is subjected to slow heating or cooling in the temperature range of 450°C-900°C, complex carbides are precipitated at the grain boundaries, which leads to chromium depletion adjacent to the grain boundaries [1,10,11]. When the concentration of chromium in the matrix becomes less than 10-11 wt%, the film of Cr_2O_3 is not passive enough to protect austenitic stainless steel and therefore it becomes susceptible to intergranular corrosion (IGC) and this phenomenon is known as sensitization [7,28-30].

Taiwade [31] investigated effect of grain size on degree of sensitization of chrome- Manganese stainless steel. As there is increase in grain size, chromium in the matrix has to travel a very long distance in order to reach towards the grain boundaries to form chromium carbide. Therefore co-relationship between the grain size and DOS was established and it resulted in minimizing the effect of sensitization

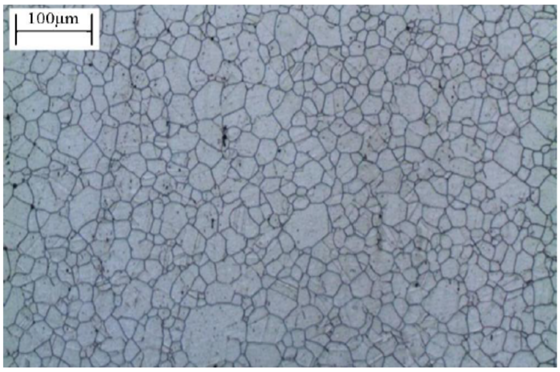

Figure 1: Microstructure of AISI 201 base metal.

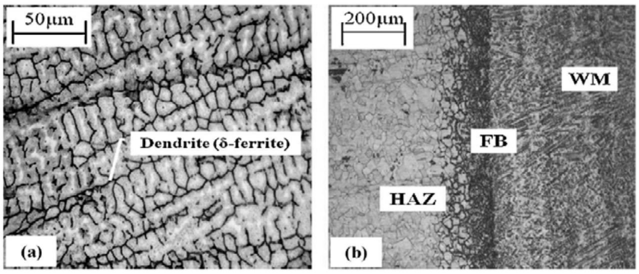

Figure 2: Microstructure of weld metals produced by welding (a) Weld metal and (b) Fusion boundary and HAZ.

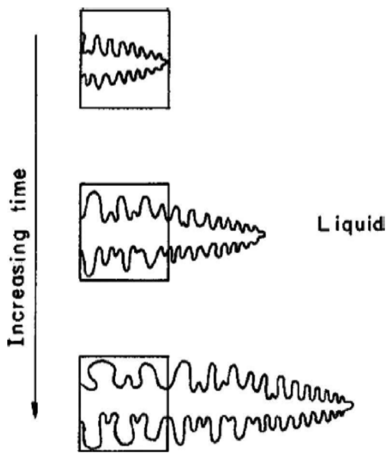

Figure 3: Schematic representation of dendrites growth.

and intergranular corrosion and found that there is reduction in width of Chromium depleted region attributed to increase in grain size and decrease in degree of sensitization (DOS).

Beltran [32] performed studies on AISI 304 SS with three different grain sizes viz. 15, 40 and 150 μm (by straining). They concluded that when the samples were heat treated from a lower aging temperature (898 K) to a higher aging temperature (1048 K), the sensitization/desensitization process occurs very rapidly for grain sizes ranging from 150 to 15 μm. The study of the effect of solution annealing treatment and sensitization on IGC behaviour of 316 SS and based on electrochemical potentiodynamic reactivation (EPR) results they concluded that degree of sensitization (DOS) decreased as solution annealing temperature and time increased. Li have evaluated the effect of grain growth on chromium carbide precipitation and IGC of 316L SS using electrochemical tests [33]. They showed that chromium carbide precipitations were much delayed in larger grains. Ravindra V Taiwade conducted systematic comparison of effect of single, double and triple pass welding on heat affected zone and tensile strength of low nickel chrome-manganese austenitic stainless steel and AISI 304 stainless steel [34]. From DLEPR results, it can be concluded that the sensitized region of AISI 304 SS is less susceptible to IGC than Cr-Mn ASS. The highest % DOS (35.53) was obtained for triple pass welding of Cr-Mn ASS. It is concluded from quantitative and qualitative tests that the Cr-Mn ASS is more susceptible to IGC as compared to AISI 304 SS for all the passes of welding. There was a significant reduction in tensile strength with increasing number of passes. However, the decrease in tensile strength is relatively more in Cr-Mn ASS as compared to AISI 304 SS.AISI 304 SS failed due to ductile fracture for all the passes of welding. In Cr-Mn ASS, mixed types of fracture was observed in single and double pass welding, whereas the intergranular fracture was observed in triple pass welding. EPMA line scan results confirmed that the minimum Cr-concentration value at grain boundary attributed to detrimental attack of IGC in HAZ in case of Cr-Mn ASS after third pass of welding. Degree of sensitization (DOS) increased with increase in number of passes and highest DOS (35.53%) was obtained for triple pass welding of low nickel chrome-manganese austenitic stainless steel.

Welding Effect of Ferritic Stainless Steel

Microstructure

Welding of Ferritic stainless steel can lead to the problem of coarse grains in the weld zone and heat affected zone of fusion zone and resulting in low ductility and toughness due to absence of phase transformation during which grain refinement may occur (Figure 4). Microstructure and chemical composition are two important characteristics of weld metal in ferritic stainless steel, which causes variation in impact, tensile and hardness properties [18].

Khorrami [35] investigated study on mechanical characteristics and microstructure of ferritic stainless steel and low-carbon steel joints. In this research, behaviour of dissimilar welding for AISI 430 ferritic stainless steel and plain carbon steel is studied, by using gas tungsten arc welding process in both conditions of autogenous and using filler rod ER309L. It was found that the microstructure of weld metal in the specimen welded by autogenous welding is fully ferrictic and with filler metal microstructure consists of duplex ferrictic- martensitic. Volume fraction of martensite and precipitates in HAZ of AISI 430 stainless steel for specimen welded with filler rod ER309L are higher than those for autogenous one. Welding heat input and its resulting cooling rate decides the composition and amount of martensite and carbides. It is found that in HAZ of AISI 430 steel welded with filler rod ER309L led to martensite with lower carbon content. Due to the formation of duplex ferritic martensitic microstructure, hardness value of weld metal in the case of using filler metal ER309L is about 2.75 times higher than that for autogenous ones.

Emel Taban [36] studied the effect of hybrid (gas tungsten arc + plasma) welding on modified type of 12% chromium ferritic stainless steel. Properties of the heat affected zone is mostly influenced by base metal and improved by proper selection of filler metals, which decides microstructural and mechanical properties of the weld bead. This is confirmed by the toughness data of weld metal which are better than those of heat affected zone for both welds. Finer grain size of ferritic stainless steel lead to improvement in toughness for the welded 12Cr ferritic stainless steels.

Nascimentoa [37] investigated the effect of Gas Tungsten Arc Welding of an AISI 4130 stainless steel on the axial fatigue strength we used in airframe, which is critical to the flight-safety And found that with increase in the number of GTAW repairs, fatigue strength is decreased with, and was related to residual stress, weld bead geometry factors and microstructural changes as well as microhardness changes. This led to increase in high stress concentration at the weld structure.

A.K.Lakshminarayanan investigated the effect of welding processes such as gas metal arc welding, shielded metal arc welding and gas tungsten arc welding on ferritic stainless steel of grade AISI 409M and studied impact and tensile properties found that gas tungsten arc welded joints of ferritic stainless steel have superior impact and tensile properties compared with gas metal arc welded joints and shielded metal arc and this is mainly due to the presence of finer grains in fusion zone and heat affected zone [38,39].

Sensitization

Stress corrosion cracking failure is result of sensitization in some ferritic stainless steels [40,41]. The major problem for using ferritic stainless steel is due to the depletion of the chromium content of the weld matrix particularly in the HAZ, which lead to susceptibility to intergranular corrosion (IGC).Due to this reason there is limited use of ferritic stainless steel regardless of its attractive economics and metallurgical attributes, combined with excellent corrosion resistance in acidic and alkali environments with moderate strength.

There are various models proposed to explain the sensitization of stainless steel like chromium depletion theory, electrochemical theory, solute segregation theory , strain theory but chromium depletion theory is the most widely accepted and has been one only proved experimently [42,43].

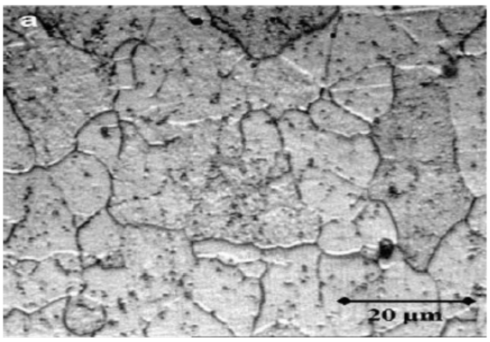

Figure 4: Microstructure of AIS409M grade base metal.

M.Du.Toit studied behaviour of stress corrosion cracking and HAZ sensitization of 1.4003 ferritic stainless steel [44]. They concluded that during welding, cooling rate acts as influencing factor for the desensitization as there is backdiffusion of chromium into the depleted regions during welding.Due to this behavior of ferritic stainless steel it can be suggested that the heat input, which influence on cooling rate is the factor to be control. For welding low heat input can be suggested for ferritic stainless steel to limit sensitization but not to eliminate it [45].

Sridhar investigated effects of welding parameters on corrosion and mechanical properties of duplex stainless steel [46]. On the basis of series of work performed, optimized heat input within the range 0.5-1.5 kJ/mm is recommended. Maximum heat input range 1 kJ/mm is provided in most literature [8], but the weld heat input must never be less than 0.5 kJ/mm [43]. However, welding speed and welding current optimized value is to be determined for proper range of range weld heat input.

Sensitization can be controlled by creating high ferrite number, control of heat input, cooling rate and control of interstitial (C + N) element in ferritic stainless steels. T.G.Gooch investigated corrosion behaviour of welded stainless steel and concluded that interstitial element in stainless steel should not be more than 0.03 wt% of carbon in order to proper control of sensitization [47].

Conclusion

Low nickel chrome-manganese austenitic and ferritic stainless steel has resulted as a cost-effective with good mechanical properties. On the basis study of the microstructural experimentation and sensitization effect of welded low nickel chrome-manganese austenitic and ferritic stainless steel following conclusions may be drawn: As evident from literatures, no dominating work has been reported on autogenous welding process on Low nickel chrome-manganese austenitic and ferritic stainless steel. So, this area is still open for future research. There is very less published work available on the study of surface crack formation, residual stresses and sensitization effect of low nickel chrome-manganese austenitic stainless steel. Which is one of the emerging economical material, with various technical properties. Reduction in toughness and ductility is due to grain growth and Sensitization effect. The mechanical properties of an welded joints is also influenced by dendrites structure. Smaller dendrites and low spacing caused by the low heat input welded joint lead to higher tensile strength. As number of welding passes increases, degree of sensitization also increases.

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