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Weld joint design and thermal aging influence on the metallurgical, sensitization and pitting corrosion behavior of AISI 304L stainless steel welds

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ABSTRACT

Experimental investigations were carried out to study the influence of weld joint design and post weld thermal aging treatments on the metallurgical, intergranular and pitting corrosion behavior of AISI 304L stainless steel welded joints. 10 mm thick linear weld joints were fabricated using gas metal arc welding process using single-V and double-V joint design with an average heat input of 503.42 J/mm and 562.78 J/mm respectively. Thermal aging of these welds was carried out at 750 °C for 0.5 h and 4 h, and the cooling media used was furnace, air and water quench (used separately for each specimen), so as to induce variable degree of carbide precipitation in different zones of these welds. Microstructural studies revealed that the extent of carbide precipitation was more in case of welds made using double-V joint design as compared to single-V joint welds. Degree of sensitization (DOS) and pitting performance of these welds evaluated using double loop electrochemical potentiokinetic re-activation (DLEPR) technique and potentiodynamic anodic polarization technique respectively, further showed that single-V joint performed better in terms of corrosion properties owing to lesser precipitation as compared to the double-V joint. This study shows that in comparison to double-V joint, single-V joint design can prove to be an important part of fabrication procedures where service conditions demand better corrosion properties of these welds.

1. Introduction

AISI 304 stainless steel, popularly known as 18/8 steel belongs to family of austenitic stainless steels finds usefulness in plethora of engineering applications owing to its moderate cost, superior mechanical performance and corrosion resistance. Typical applications of this steel include its use for storing and transportation of liquefied natural gas (LNG) whose boiling point is −162 °C under 1 atmosphere, bellows used for conduit for liquid fuel and oxidizer in propellant tank of satellite launch vehicle, cryogenic structures [1–3]. AISI 304L is an exclusive modification of AISI 304 stainless steel by keeping carbon percentage below 0.03%. Type 304 and 304L are used to the extent of more than 20,000 tons a year [4].

Despite of its widespread industrial usage, there are various metallurgical phenomena which continue to adversely affect its engineering performance during various service applications [5]. One of such problems encountered is sensitization which occurs during thermal exposition of this alloy to temperature range of 600–850 °C, where carbon from the matrix combines with chromium to form $Cr_{23}C_6$ at grain boundaries, thus making areas adjacent to grain boundaries scarce in chromium content and these areas then become severely susceptible to attack by corrosive environment thus depreciating corrosion resistance [6,7].

Weld joint design is an essential part of any welding procedure specification (WPS) for components required to be welded in a production route. Prior to carrying out welding, groove formation by beveling of edges is done by machining operation. Grooves thus formed are filled by filler material which may or may not be same as base material during welding. Choice of weld joint design takes into account weld quality and productivity.

Effects of weld joint design on performance related aspects like mechanical properties, formation of residual stresses etc. in case of welds have been investigated by various researchers. A study on the effect of different groove designs on quenched and tempered steel welded joints show that joint design variation can exert a strong influence on the mechanical properties of the welds thus indicating that joint design variation plays a strong role on the cooling characteristics of such welds [8]. A comparative evaluation between single-V and double-V weld joints of quenched and tempered steel in terms of ballistic performance was reported by Balakrishnan et al. [9] wherein

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double-V joint exhibited superior resistance to bullet penetration at the weld metal location without any bulge at the rear side than single-V joint. Effects of weld groove shape and number of passes on the residual stresses in butt-welded pipes were investigated by Sattari-Far et al. [10]. Assessment of weld pool behavior and weld bead geometry pertaining to different groove angles was done by Chen J. et al. [11]. In another work reported by Ling K.H. et al. [12], investigations were carried to study the influence of different groove configurations on mechanical and metallurgical properties of JIS SS4400 structural steel flux cored arc welds. Variations in mechanical and impact behavior was observed corresponding to different joint configurations attributable to varying level of grain refinement achieved due to variations in thermal characteristics of heat input/dissipation.

It is very evident on the basis of literature reviewed that joint design affects the heat input/dissipation characteristics of the welds which can influence the mechanical properties in a rather significant manner. It is observed that no research work is available which reports about the effect of joint design on the corrosion behavior of these welds. Since this alloy is meant for high temperature applications, corrosion resistance is considered to be a vital performance characteristic for any fabrication. Such an investigation is needed keeping in view the severe effects of the sensitization phenomenon on the behavior of welds during high temperature service applications. This was the motivation to carry out this research work.

The present work aims at formulating a comparative study such that the influence of two joint variations viz. single-V and double-V on the metallurgical, sensitization and pitting corrosion performance of AISI 304L welds could be studied. This would be beneficial in strengthening the data base related to welded fabrications where this alloy is used under corrosive environments.

2. Materials and experimental procedure

2.1. Base and filler material combination

AISI 304L stainless steel in the form of rolled plates of sizes 250 mm × 50 mm × 10 mm was used as base material in the present work. The filler used was ER 308L SS solid electrodes of diameters 2.5 mm and 1.2 mm for accomplishing root pass and cover passes respectively. The base metal's chemical composition was analyzed using an optical emission spectrometer (Model: Solaris CCD Plus, Italy), whereas the filler metal's composition was taken directly from the supplier as per the requirements of the welding procedure. Elemental composition details of the base and the filler material are presented in Table 1.

2.2. Welding procedure

Two different joint designs viz. single-V and double-V were machined on as received base plates before carrying out the welding operation and are schematically shown in Fig. 1. These configurations were used for welding two set of plates, which inherently resulted into change of groove volume, thus necessitating that adequate parametric combinations be used for welding, so as to achieve welds of sound industrial quality. So, heat input variation was not intended in the present work, instead the methodology was to fabricate joints such that the objective of studying the influence of joint design variation on the metallurgical and corrosion properties of these welds could be achieved. Base plates were thoroughly cleaned before welding so as to avoid any kind of defect resulting from any possible source of contamination like rust, scale, moisture etc. Root passes in both the weld joints were accomplished by using gas tungsten arc welding (GTAW) process. Pure argon was used as shielding gas and interpass temperature was maintained around 150 °C. Middle and cover passes in both the weld joints were completed using gas metal arc welding (GMAW) process. Heat source efficiencies for calculating heat input per unit length of the welds for GMAW and GTAW were taken as 0.8 and 0.7 respectively [13]. Average heat inputs per pass were 503.42 J/mm and 562.78 J/mm for single-V and double-V weld joint respectively. Process parameters used for fabricating single-V and double-V weld joints are presented in Tables 2 and 3 respectively.

2.3. Specimen sampling

Test specimens for carrying out metallurgical studies and corrosion testing were machined out using a wire cut electro-discharge machine, thus ensuring that there is no degree of cold work by cutting forces as in case of conventional machining as cold working contributes to sensitization in austenitic stainless steels [14]. Actual photographs of welded plates and extracted specimens after machining for various studies are shown in Figs. 2 and 3 respectively.

2.4. Post weld thermal aging of the welds

Weld specimens were subjected to thermal exposition at 750 °C for 0.5 h and 4 h followed by three different cooling modes viz. furnace, air and water quench for inducing variable degree of carbide precipitation. The details for the same are presented in Table 4.

2.5. Metallurgical studies

Metallurgical optical microscope equipped with image capturing software was used to study microstructural characteristics of the welds at various zones of interest corresponding to different experimental conditions. Specimens were polished using emery paper belts with grit size upto 2000 and subsequent polishing using diamond paste. Chemical etching was done in 10 g $FeCl_3$ + 30 ml HCl + 120 ml distilled water [15] using immersion and subsequent swabbing. Vickers microhardness testing was carried out on the welds to study the microhardness variation in these welds as per ASTM Standard E384 [16]. A load of 500 g and dwell time of 20 s were used in tests.

2.6. Degree of Sensitization (DOS) studies

For assessing the sensitization behavior of different welds of AISI 304L stainless steel, double loop electrochemical potentiokinetic reactivation (DLEPR) technique was employed in accordance with ASTM Standard G-108 [17]. Each weld specimen contained two weld cross sections (on both the sides) and each of these surfaces was subjected to electrochemical tests using the same set of testing conditions. This facilitated corrosion data extraction from the same specimen tested by exposing two fresh surfaces, rather than going for test repetition from the same surface. During welding, heat input inconsistencies can arise out due to two reasons, firstly welding arc is highly dynamic in nature and secondly GTAW process has been used in the manual mode. So it was expected that, there would exist a point to point variation in terms

Table 1
Chemical composition of the base and filler material (wt.%).

Element	C	Si	Mn	P	S	Cr	Mo	Ni	Co	Ti	V	Fe
Base materialAISI 304L SS	0.030	0.430	1.68	0.0312	0.004	18.57	0.304	8.31	0.144	0.008	0.061	Balance
Filler materialER 308L SS	0.028	0.421	1.42	0.021	0.012	19.15	0.256	10.02	–	0.003	0.032	Balance