Effect of Welding Passes on Heat Affected Zone and Tensile Properties of AISI 304 Stainless Steel and Chrome-Manganese Austenitic Stainless Steel

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This paper aims at a systematic comparison of effect of single, double and triple pass welding on heat affected zone and tensile strength of AISI 304 stainless steel and chrome-manganese austenitic stainless steel. Degree of sensitization (DOS) increased with increase in number of passes and highest DOS (35.53%) was obtained for triple pass welding of chrome-manganese austenitic stainless steel. The decrease in tensile strength is relatively more in chrome-manganese austenitic stainless steel as compared to AISI 304 SS. The mode of failure for AISI 304 SS was ductile fracture, whereas chrome-manganese austenitic stainless steel failed due to intergranular brittle fracture.

KEY WORDS: AISI 304 stainless steel; chrome-manganese austenitic stainless steel; shielded metal arc welding; heat affected zone; fractography; electron probe micro analysis.

1. Introduction

Austenitic stainless steels (ASS) have wide applications in many industries due to its excellent combination of corrosion resistance and mechanical properties.^{1,2)} Corrosion resistance is provided by a very thin invisible passive film of Cr_2O_3 , formed on the surface of ASS, when exposed to ambient environment.³⁾ The ASS family is classified into two categories viz. 300-series and 200-series stainless steels. AISI 304 and 316 SS are the most popularly used grades of 300-series stainless steel.^{1,4)} In 200-series, manganese is introduced in addition to nickel, which acts as an austenite stabilizer, and hence the nickel content in 200-series is lower than in 300-series.^{5,6)} 200-series steels are economical than 300-series, but they do not have same level of corrosion resistance and weldability as compared to 300-series.⁷⁾ 200-series is the fastest growing variety of stainless steels in recent years and currently account for more than 10% of the total stainless steel production.^{8,9)} The future will place greater demands on 200-series alloys in replacement of 300-series for variety of applications such as home accessories, office appliances, light poles, construction, outdoor installations, etc., where high corrosion resistance is not required.^{1,7,9,10)} These steels are also known as “Chrome-Manganese” ASS (Cr–Mn ASS).¹⁰⁾ When the ASS family is subjected to slow heating or cooling in the temperature range of 450°C–900°C, complex carbides (Fe, Cr)₂₃C₆ are

precipitated at the grain boundaries. This leads to chromium depletion adjacent to the grain boundaries.^{1,11,12)} 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 ASS and therefore it becomes susceptible to intergranular corrosion (IGC) and this phenomenon is known as “sensitization”.^{12,13)}

Welding is the most common fabrication process used for ASS in various industries. ASS is generally considered to have very good weldability.¹⁴⁾ Shielded metal arc welding (SMAW) and tungsten inert gas welding (TIG) are the most commonly used welding process for ASS.^{14,15)} During welding, a certain portion of base metal experiences peak temperatures high enough to develop microstructural changes viz. phase-transformation, grain growth, etc. These microstructural changes have detrimental effects on the mechanical properties of weldment. This part of base metal is commonly referred to as “Heat Affected Zone (HAZ)”. In case of ASS, chromium carbide precipitates along grain boundaries in the HAZ, which leads to IGC.^{4,15–17)} Various researchers have studied the effect of welding on the formation of HAZ in 300-series ASS.^{18–21)} Subodh Kumar *et al.*²²⁾ studied the effect of three different heat inputs on the microstructure and mechanical properties of gas tungsten arc welded AISI 304 stainless steel joints. They concluded that the tensile strength decreases with increase in heat input. But, the literature related to welding behavior and subsequent mechanical properties of 200-series ASS is scanty till now. The authors in their previous work⁵⁾ carried out studies on bead-on-plate welding with single heat input on Cr–Mn ASS and

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concluded that it gets sensitized during welding and width of HAZ was measured as 2 mm. As already mentioned, the corrosion behavior and mechanical properties of Cr-Mn ASS is not same as in 300-series, hence, the authors were interested to investigate the welding behavior of both the steels for single and multipass welding, and also the tensile properties of the welded steels.

2. Experimental Work

The AISI 304 SS and Cr-Mn ASS were procured from market in the form of sheet. Their typical chemical composition as determined by optical emission spectrometer is presented in **Table 1**. Plates of size 150 mm × 75 mm × 3 mm were obtained using wire-cut electrical discharge machine (WEDM) from AISI 304 SS (3 Nos.) and Cr-Mn ASS (3 Nos.). These plates were solution annealed in muffle furnace at a temperature of 1050°C for 1 hour, followed by water quenching.²³⁾ Then, the plates were polished up to 600 grit to remove oxide layer formed due to solution annealing. Bead-on-plate SMAW was performed along the centre line (see **Fig. 1**) of the solution annealed plates using the electrode “AWS E308L-16” of diameter 3.15 mm.²⁴⁾ The electrodes were baked at 200°C in the oven for 45 minutes before welding, to remove moisture. Single, double and triple passes were carried out at a uniform speed by an experienced welding operator. Two minutes rest time was given between the successive passes.²⁵⁾ The slag formed during welding was removed in this rest time. The heat input was kept constant for all the passes. Heat input per mm length of weld ‘Q’ was calculated using welding variables and by considering arc efficiency (η) of 0.75.^{15,25)}

$$Q = (\eta V I / v) \dots\dots\dots (1)$$

where, “V” is arc voltage in volts (V),

“I” is welding current in amperes (A),

“v” is speed of welding in mm/s.¹⁷⁾

Following welding parameters were used in this study:

Table 1. Chemical composition (wt%) of studied steels.

Elements Steel	C	Cr	Ni	Mn	Si	P	S
AISI 304 SS	0.054	20.01	7.97	1.11	0.510	0.0281	0.0061
Cr-Mn ASS	0.11	15.86	0.3098	9.60	0.434	0.0378	0.0041

Fig. 1. Bead-on-plate shielded metal arc welding.

Welding current – 75 A, arc voltage – 35 V and welding speed (v) – 2.57 mm/s.

Three samples of size 150 mm × 10 mm × 3 mm were obtained carefully from the welded plate using WEDM. These samples were denoted by A, B and C as shown in **Fig. 1**. O–O’ denotes the centre line of welded plate. The remaining part of the plate was discarded to neglect the initial and end effect of heat input. In order to see the effect of number of passes on HAZ on top surface and in cross section, the samples of size 50 mm × 10 mm × 3 mm from “B” and “C” denoted by ‘X’ and ‘Y’ respectively were carefully cut using WEDM as shown in **Fig. 1**.

The sample preparation for “X” and “Y” is as follows. A copper strip was fixed to one side of sample using silver paste and a copper wire was soldered to the copper strip for electrical connections. The other side was kept open for etching and electrochemical tests. The assembly was then mounted in cold setting resin. The open surface of sample was polished on emery papers (180, 240, 400, 600 and 800 grit), and then on velvet cloth smeared with 0.75 μ alumina (Al_2O_3) slurry. The samples were ultrasonically cleaned in distilled water at each stage of polishing. To identify the fusion zone and HAZ, surface area of 50 mm × 10 mm in case of top surface and 50 mm × 3 mm in case of cross-section respectively was used for electrolytic etching by ASTM standard A-262 Practice A. In Practice A, the samples were electrolytically etched in 10 wt% oxalic acid solution with current density of 1 A/cm² for 90 seconds.²⁶⁾ Surface area of 10 mm × 10 mm and 35 mm × 3 mm of sample ‘X’ and “Y” respectively was exposed for etching and remaining part of the samples was protected using teflon tape, which was also then etched in similar manner. The samples were then examined under optical microscope (*Zeiss Axiolab*) and scanning electron microscope (*JEOL 6380A*).

Double loop electrochemical potentiodynamic reactivation (DLEPR) test was performed in the sensitized region of true HAZ (refer **Fig. 3**) in the sample “Y”, which was identified by Practice A. The test was carried out in a solution consisting of 0.5 M H_2SO_4 + 0.01 M NH_4SCN at room temperature (27°C) using Potentiostat (*Solartron-1285*). A conventional three-electrode electrochemical cell with platinum electrode as counter electrode, saturated calomel electrode (SCE) as the reference electrode and sample as working electrode was employed. Before exposing working electrode, the test solution was de-aerated using dry (oxygen free) nitrogen gas for 1 hour. The experiments were initiated after nearly steady-state open circuit potential (OCP) had reached (about 45 min). The test was performed at scan rate of 6 V/h and the potential range was from –500 mV (SCE) to +300 mV. This gives the forward scan. The scanning direction was then reversed, and the potential was then reduced back to –500 mV to obtain reverse scan. The peak activation current density (I_a) and the peak reactivation current density (I_r) were measured during forward and reverse scans, respectively. The % DOS (degree of sensitization) was then computed as the ratio of (I_r/I_a) × 100.^{27–29)}

The remaining sample ‘A’ was polished up to 600 grit, ultrasonically cleaned with distilled water. Then these samples were subjected to ASTM standard A-262 Practice E test (Strauss test).²⁶⁾ In Practice E, the samples were exposed in boiling solution of 16% H_2SO_4 + 100 g/l CuSO_4 (in pres-

Fig. 2. SEM micrographs of welded Cr-Mn ASS as per ASTM standard A-262 Practice A: a) step structure b) dual structure c) ditch structure.

Fig. 3. Optical Micrographs as per ASTM standard A-262 Practice A test a) AISI 304 SS b) Cr-Mn ASS.

Fig. 4. Schematic of various regions of weldment.

ence of Cu turnings) for 24 hours. After that, the samples were removed, rinsed with distilled water, dried and stored in desiccators. Then they were subjected to tensile tests. The tensile specimens had gauge length of 50 mm and they were fractured in an *INSTRON 4467* with a cross head speed of 10 mm/min. The fractured surfaces of the tensile specimens were studied using *SEM JEOL 6380 A*. All specimens were examined at an acceleration voltage of 20 kV.

The chemical composition of the alloying elements across the grain boundaries was obtained using Electron Probe Micro analyzer (EPMA). The EPMA line scans of HAZ in cross-section of welded AISI 304 SS and Cr-Mn ASS after third pass was obtained in conjunction with SEM using *JEOL 8600M Electron Probe Micro analyzer*. The scan was performed for a set of 25 data points.

3. Results and Discussion

Typical SEM micrographs of step, dual and ditch structures as per ASTM standard A-262 Practice A test are shown in **Figs. 2(a)–2(c)**. They are classified as follows²⁶⁾

1. Step structure: Steps only between grains, no ditches at grain boundaries.
2. Dual structure: Some ditches at grain boundaries in addition to steps, but no single grain completely surrounded by ditches.
3. Ditch structure: One or more grain completely surrounded by ditches.

Figures 3(a) and 3(b) shows the optical micrograph of solution annealed AISI 304 SS and Cr-Mn ASS after etching as per ASTM standard A-262 Practice A test. It is observed that both the steels before subjected to welding have single phase austenitic structure and no traces of carbides are found.

3.1. Microstructural Study of Top Surface

Figure 4 shows the schematic representation of various regions of welded plate. The microstructures obtained

showed a similar pattern as shown in figure. The true HAZ includes the region where microstructures have been altered due to both grain coarsening and carbide precipitation. Generally, the true HAZ is adjacent to the fusion boundary. The width of sensitized region in HAZ is a part of true HAZ, where only carbide precipitation has taken place. For ASS, the sensitized region is a serious cause of concern because numerous failures occur in this particular region as the steel is susceptible to IGC.^{12,13)}

Considering the fusion boundary as a reference, the microstructures were observed at every 1 mm distance on the welded plate along longitudinal direction in order to identify the HAZ. **Figures 5(a)–5(f)** shows the optical micrographs of top surface of AISI 304 SS and Cr-Mn ASS for single, double and triple passes. The details obtained from the microstructures viz. true HAZ and width of sensitized region in HAZ are presented in **Table 2**. Figures 5(a)–5(b) shows the grain coarsening in both the steels when subjected to single pass, but no traces of carbides can be seen. From Table 2, it can be seen that the true HAZ for single pass welding of both the steels is 2 mm, and no sensitized region in true HAZ was present. Hence, only grain coarsening was observed on the top surface when submitted to single pass welding. Thus, for the given heat input, both the steels are not prone to sensitization on the top surface during single pass welding.

However, a partial attack of carbide precipitation (dual structure) is observed when the steels are subjected to double pass welding (see **Figs. 5(c)–5(d)**). The severity of attack is less in AISI 304 SS as the grain boundaries are observed to be very thin as compared to Cr-Mn ASS. The true HAZ in AISI 304 SS included only sensitized region of 3 mm (see Table 2). For Cr-Mn ASS, true HAZ is spread over a distance of 5 mm from fusion boundary and grain coarsening was observed till 2 mm from fusion boundary, and the sensitized region was 3 mm. Figures 5(e)–5(f) shows the micrographs after triple pass welding. A lightly attacked ditch structure was observed in case of AISI 304 SS, whereas a

Fig. 5. Optical micrographs of top surface as per ASTM standard A-262 practice A test for single pass (a-b); double pass (c-d); triple pass (e-f).

Table 2. Data obtained from microstructures of top surface.

Steel	Number of Passes	True HAZ (mm)	Width of Sensitized region in HAZ (mm)
AISI 304 SS	Single	2	0
	Double	3	3 (dual)
	Triple	5	5 (lightly ditch)
Cr-Mn ASS	Single	2	0
	Double	5	3(dual)
	Triple	9	6 (heavily ditch)

fully ditch structure for Cr-Mn ASS was observed. Also, the sensitization region for Cr-Mn ASS was measured to be 6 mm, whereas for AISI 304 SS it was 5 mm.

Hence, it can be seen that the low-level intensity of attack is increasing from single to triple pass welding for given heat input for both the steels. But, still no inferences can be drawn based only on the micrographs of top surface. So, a detailed study of cross-section of the welded plate has been carried out.

3.2. Microstructural Study of Cross-section

Figures 6(a)–6(f) shows the optical micrographs of cross-section of AISI 304 SS and Cr-Mn ASS for single, double and triple passes. From Figs. 6(a), 6(c) and 6(e), it can be confirmed that for AISI 304 SS, the extent of carbide precipitation increases with increase in number of passes. That is the AISI 304 SS when subjected to triple pass welding, gets highly sensitized. A similar trend can be seen in case of Cr-Mn ASS. From Figs. 6(a)–6(b) and **Table 3**, it can be noticed that a dual structure is observed over a region of 4 mm and 2 mm for AISI 304 SS and Cr-Mn ASS, respec-

Fig. 6. Optical micrographs of cross-section as per ASTM standard A-262 practice A test for single pass (a-b); double pass (c-d); triple pass (e-f).

Fig. 7. SEM micrographs of cross-section as per ASTM standard A-262 practice A test after third pass of welding.

Table 3. Data obtained from microstructures of cross-section.

Steel	Number of Passes	True HAZ (mm)	Width of Sensitized region in HAZ (mm)
AISI 304 SS	Single	5	4
	Double	7	7
	Triple	8	8
Cr-Mn ASS	Single	5	2
	Double	8	4
	Triple	11	7

tively. For double and triple pass welding in AISI 304 SS (from Table 3), no grain coarsening was observed and sensitized region was spread over 7 mm and 8 mm respectively. From Figs. 6(d) and 6(f) and Table 3, the values of true HAZ and width of sensitized region indicate that there was grain coarsening near the fusion boundary, whereas a rigorous attack of carbide precipitation can be seen for double and

triple pass welding in Cr-Mn ASS.

Figures 7(a) and 7(b) shows SEM micrographs of cross-section of AISI 304 SS and Cr-Mn ASS after third pass of welding. The micrographs confirm the existence of Cr-carbides at the grain boundaries. The severity of Cr-carbide precipitation at grain boundaries is more in case of Cr-Mn ASS than AISI 304 SS, after third pass of welding.

Therefore, it is concluded from optical and SEM micrographs, that the Cr-Mn ASS is highly susceptible to IGC for

all the passes of welding, but the extent of Cr-depletion is very high in Cr-Mn ASS after third pass.

3.3. Results of DLEPR Test

Figures 8(a) and 8(b) shows the DLEPR curves for solution annealed AISI 304 SS and Cr-Mn ASS respectively. The activation peak current density (I_a), reactivation peak current density (I_r) and % DOS are presented in **Table 4**. The I_r value for Cr-Mn ASS is nearly one order magnitude

Fig. 8. DLEPR curves for solution annealed: a) AISI 304 SS b) Cr-Mn ASS.

Fig. 9. DLEPR curves of cross-section for single pass (a-b); double pass (c-d); triple pass (e-f).

more than that of AISI 304 SS. The development of the reactivation peak current density can be attributed to metal dissolution during reverse scan. This means that the passive film formed on the surface of Cr–Mn ASS has lower corrosion resistance as compared to AISI 304 SS. A ratio of maximum current generated in the DLEPR test (I_r/I_a) is used as a measure for the “degree of sensitization (DOS)”.³⁾ The % DOS of solution annealed Cr–Mn ASS shows value of 2.92, whereas for AISI 304 SS, it is 0.17%. But, from Figs. 3(a) and 3(b), it can be seen that both the steels when solution annealed have single phase austenitic structure. The exceptionally high value of % DOS in Cr–Mn ASS was due to the less amount of % Cr present in this steel.

The optical micrographs of welded samples in cross-section showed significant results in terms of sensitized region in true HAZ. But, the micrographs give only the nature of sensitization viz. step, dual or ditch, or in other words, it only provides the qualitative information. Therefore, quantification of sensitized region was carried out in terms of % DOS. The DLEPR curves of cross-section for single, double and triple pass welding of both the steels are shown in Figs. 9(a)–9(f). The results obtained from these curves are presented in Table 4.

The I_r values increases with increase in number of welding passes in case of both the steels. It indicates that the passive film is easily dissolved in triple pass than in single and double passes. It is also evident in the form of % DOS, that

Table 4. Data obtained from DLEPR curves.

Number of passes	I_r (A/cm ²)	I_a (A/cm ²)	%DOS
AISI 304 SS			
Solution Annealed	0.000130	0.077034	0.17
Single pass	0.003183	0.075629	4.20
Double pass	0.011061	0.15265	7.24
Triple pass	0.013001	0.082212	13.38
Cr–Mn ASS			
Solution Annealed	0.001731	0.595287	2.92
Single pass	0.003821	0.060848	6.27
Double pass	0.006646	0.061315	10.83
Triple pass	0.011912	0.033535	35.53

Fig. 10. Relationship between number of passes and % DOS of cross-section.

is, the % DOS for triple pass welding is higher than the other passes (see Table 4). These results are in good agreement with the optical and SEM micrographs of cross-section (see Figs. 6(a)–6(f) and 7(a)–7(b)).

The effect of number of passes on % DOS of cross-section for AISI 304 SS and Cr–Mn ASS is plotted and presented in Fig. 10. From Table 4, for single pass welding, the % DOS values are 4.20 and 6.27 for AISI 304 SS and Cr–Mn ASS respectively. It means that the sensitized region of Cr–Mn ASS which was exposed in DLEPR test is more susceptible to IGC as compared to AISI 304 SS. Similar inferences can be drawn for double and triple pass welding. Amongst sensitized regions of all the passes, the highest % DOS (35.53) was obtained for triple pass welding of Cr–Mn ASS. This can also be correlated with its micrograph (see Figs. 6(f) and 7(b)).

Hence, from qualitative and quantitative tests, it is concluded that Cr–Mn ASS is more susceptible to IGC as compared to AISI 304 SS, when subjected to welding. Cr–Mn ASS was badly affected due to IGC in HAZ because of its high carbon and low chromium content. This ill-effect of sensitization will be reflected in the mechanical properties. The next section deals with effect of number of passes on the tensile strength of both the steels.

3.4. Tensile Test and Fractography

The effect of number of passes on the tensile properties of AISI 304 SS and Cr–Mn ASS was studied by performing tensile tests on the welded samples. The variation in the tensile strength of both the steels with number of passes is depicted in Fig. 11.

It can be seen that there is 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. The tensile strengths of solution annealed specimen of AISI 304 SS and Cr–Mn ASS are 562 MPa and 626 MPa respectively. The tensile strengths of AISI 304 SS were obtained as 530, 505 and 460 MPa, whereas for Cr–Mn ASS, they were 561, 503 and 406 MPa, when subjected to single, double and triple pass of welding respectively. The reduction in tensile strength with the number of passes can be attributed to increase in chromium carbide precipitation in the sensitized zone, which can be

Fig. 11. Relationship between tensile strength and welding pass.

Fig. 12. SEM fractograph of the tensile specimen for single pass (a-b); double pass (c-d); triple pass (e-f).

observed from the micrographs of cross-section. This reduction is also due to the increase in severity of IGC during E test. The minimum tensile strength value was obtained for triple pass welding of Cr-Mn ASS, whose % DOS was also observed to be the highest.

The fractured surfaces of the tensile specimens of welded AISI 304 SS and Cr-Mn ASS were observed to characterize the failure modes and the SEM fractographs are shown in Figs. 12(a)–12(f). From the fractographs, it was observed that AISI 304 SS failed due to ductile fracture. The fractured surfaces of AISI 304 SS showed wide range of dimple sizes of equiaxed type (see Figs. 12(a), 12(c) and 12(e)). The dimple structure formation takes place due to micro void initiation around the carbide particles which are precipitated along the grain boundary during sensitization. In case of single pass welding, dual nature of carbide precipitation was observed in the sensitized zone (see Fig. 6(a)) and hence fine dimples were found, whereas the dimple size increase subsequently for double pass and triple pass of welding.

Figures 12(b), 12(d) and 12(f) shows the fractured surfaces of welded Cr-Mn ASS. A mixed type of fracture was observed in case of single and double passes welding, whereas the intergranular brittle fracture was observed in triple pass welding. In single pass welding (see Fig. 12(b)), intergranular brittle fracture is dominant along with slight ductile fracture. Intergranular brittle fracture was observed due to variation in segregation of carbide particles at grain boundaries, whereas very fine dimples indicate the ductile

Fig. 13. EPMA line scan to identify Cr concentration of HAZ in cross section after third pass of welding.

fracture. In double pass welding (see Fig. 12(d)), intergranular brittle fracture and transgranular cleavage was observed. The transgranular cleavage is characterized by river pattern. Secondary fracture was also observed at few places where the grain boundaries were highly attacked by carbide precipitation. In case of triple pass welding, the attack of carbide precipitation at grain boundaries was very high, and continuous, and hence it failed due to intergranular brittle fracture. The secondary fracture can be predominantly seen in triple pass welding, and it was responsible for the decreased tensile strength.

The chemical composition of the alloying elements across

the grain boundaries was obtained using Electron Probe Micro analyzer (EPMA). **Figure 13** shows the Chromium depletion of HAZ in cross-section after third pass of welding of AISI 304 SS and Cr–Mn ASS. The Cr-depleted region for Cr–Mn ASS is much wider than that of AISI 304 SS. The minimum Cr-concentration at the grain boundary in the depleted region for AISI 304 SS and Cr–Mn ASS is ~15.3 wt% and ~9 wt% respectively. The minimum Cr-concentration drops significantly, which is attributed to detrimental attack of IGC in HAZ in case of Cr–Mn ASS. The EPMA line scan results are also in good agreement with % DOS (35.53) in HAZ for triple pass welding of Cr–Mn ASS. From these results it is concluded that the passive protective oxide film of Cr₂O₃ became very weak for Cr–Mn ASS after third pass of welding. This is due to the fact that carbon content is very high in Cr–Mn ASS (C - 0.11 wt%) as compared to AISI 304 SS (C - 0.054 wt%). This high C content in Cr–Mn ASS increases the kinetics of sensitization in HAZ and therefore Cr-carbides precipitated at a very faster rate at the grain boundaries after third pass of welding.

4. Conclusions

(1) In case of top surface, for all the passes of welding AISI 304 SS did not show any significant carbide precipitation and grain coarsening, whereas fully ditch structure and significant grain coarsening for Cr–Mn ASS was observed only after triple pass of welding.

(2) In case of cross section, the extent of carbide precipitation increased with increase in number of passes for both the steels. But, the severity of carbide attack was more in Cr–Mn ASS, although the width of sensitized region was less as compared to AISI 304 SS.

(3) From DLEPR results, it is concluded that the sensitized region of Cr–Mn ASS is more susceptible to IGC than AISI 304 SS. The highest % DOS (35.53) was obtained for triple pass welding of Cr–Mn ASS.

(4) It is concluded from qualitative and quantitative tests that the Cr–Mn ASS is more susceptible to IGC as compared to AISI 304 SS for all the passes of welding.

(5) 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.

(6) 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.

(7) 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.

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