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Influence of multipass welding procedures and thermal aging conditions on the impact toughness of AISI 316 austenitic stainless steel butt welded joints

Ranjit Singh
Research Scholar, Department of Mechanical Engineering,
Desh Bhagat University, Mandi Gobindgarh, Punjab, India

Sukhwinder Singh Jolly
Professor, Department of Mechanical Engineering,
Sri Guru Granth Sahib World University, Fatehgarh Sahib, Punjab, India.

Abstract

Experimental investigations were carried out to study the influence of using different welding procedures as well as different post weld thermal aging conditions on the impact toughness of AISI 316 stainless steel joints. 10 mm thick AISI 316 L stainless steel plates were welded using GMAW (gas metal arc welding) process where procedural variations involved using a three pass weld and a five pass welding procedure for fabricating sound butt joints. Charpy V-notch testing was carried out (at the room temperature as well as cryogenic temperature), to examine the role of heat input variation that resulted due to multipass effect, on the impact toughness of the weld metal as well as the HAZ (heat affected zone) of these joints. The findings of the present work show that the five pass welding procedure resulted into higher CVN values as compared to the three pass weld. So based upon the present work it is recommended that the welding industry involved in AISI 316 SS fabrications should preferably use those welding procedures which give low heat input per unit length per weld pass if better toughness performance from these joints is desired.

Keywords: AISI 316 austenitic stainless steel, GMAW process, Impact toughness, Welding procedures, Heat input

INTRODUCTION

Stainless steel is the term used to describe an extremely versatile family of engineering materials, which are selected primarily for their corrosion and heat resistant properties. Stainless steels constitute a group of high-alloy steels based on the Fe-Cr, Fe-Cr-C, and Fe-Cr-Ni systems. Many industrial applications that use austenitic stainless steels include food preparation equipment particularly in chloride environments, pharmaceuticals, marine applications, medical implants, including pins, screws and orthopedic implants like total hip and knee replacements, fasteners, electrical, aerospace, piping, petroleum etc. [1, 2, 3].

ASS grades have been successfully welded using different welding processes [4, 5, 6]. Mechanical properties of grade AISI 316 made using powder metallurgy and injection molded have been reported [7, 8].

Despite of this reported literature, there exists a gap in terms of evaluating the effect of weld procedure variations in terms of number of welding passes as this proves to be quite an important consideration when welding procedures of welding of such steels are designed.

In view of their industrial importance and to cover the existing research gaps, the present work was planned with an aim of developing welding procedures capable of giving sound quality joints which would perform satisfactorily in actual service conditions.

EXPERIMENTAL DETAILS

Base and filler combination used

Base material used in the present work was 10 mm thick AISI 316 stainless steel rolled plates whose chemical composition is given in Table 1, were cut to suitable sizes (500 mm × 100 mm ×10 mm).

Table 1: Chemical composition of the base material (wt %)

Grade	**C**	**Mn**	**Si**	**Cr**	**Ni**	**Mo**	**S**	**P**	Fe
316L	0.03	1.50	0.47	16.90	11.00	2.35	0.01	0.03	rest

GMAW stainless steel filler wire roll of grade 316L of 1.2 mm diameter was used for giving the min weld passes whereas for the root run, GTAW filler metal wire of the same grade but of 3.4 mm diameter was used. Industrially pure argon gas (99.99% pure) was used for welding with GTAW as well as GMAW welding process.

Welding procedure

A single-V joint design as shown in Fig. 1, was used for both the plates which were machined to achieve suitable groove formation. First of all, root run was made with GTAW process for both the joints. V-grooves were prepared using a vertical milling machine. Both the plates were pre-cleaned prior to welding to remove any possible source of contamination. The welding procedures used for welding these plates are mentioned in Table 2 and 3 for the joint with 3 pass and 5 pass weld respectively.

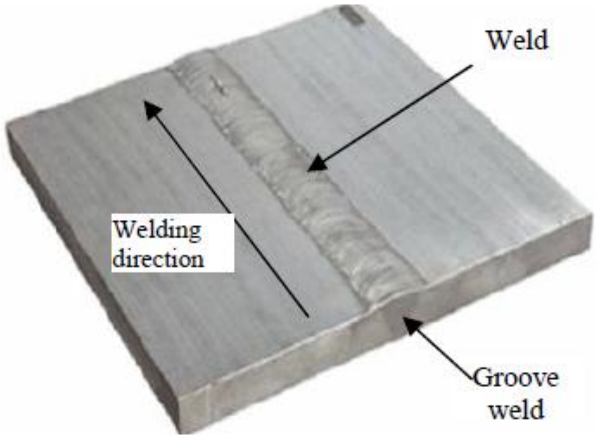

Figure 1: Actual image of the butt weld using Single-V joint design in the present work

Specimen sampling

CVN specimens of sizes 55 mm × 10 mm × 10 mm, in accordance with the ASTM E 23 standards, were extracted from both the butt welded plates as shown schematically in Fig. 2 and machined to standard size.

Post weld thermal aging of impact specimens

After extraction of specimens from the welds, post weld heat treatments were given to the specimens as shown in Table 4. The specimens were heated in the muffle furnace and upon reaching the desired temperatures were allowed to cool in the furnace itself.

Table 2: Welding conditions used for fabricating 3-pass butt weld

Weld pass no.	Welding Process used	Welding Parameters used		
		Current	Voltage	Speed
1.	GTAW Process Root pass	120 Amps	18-20 Volts	24 cm/min.
2.	GMAW Process 1st Weld pass	180-200 Amps.	22 Volts	20 cm/min.
3.	GMAW Process 2nd Weld pass	210-220 Amps.	25 Volts.	20 cm/ min
4.	GMAW Process 3rd Weld pass	220-230 Amps.	27 Volts.	18 cm/min.
Gas flow rate for GTAW and GMAW was 15l/min and 20 L/min respectively.				

Table 3: Welding conditions used for fabricating 5-pass butt weld

Weld pass no.	Welding Process Used	Welding Parameters		
		Current	voltage	speed
1.	GTAW Process Root pass	120 Amps	18-20 Volts	24 cm/min.
2.	GMAW Process 1st Weld pass	180-200 Amps.	22 Volts	20 cm/min.
3.	GMAW Process 2nd Weld	210-220 Amps.	25 Volts.	22 cm/ min
4.	GMAW Process 3rd Weld pass	220-230 Amps.	27 Volts.	24 cm/min.
5	GMAW Process 4th Weld pass	230 Amps.	27 Volts.	24 cm/min.
6.	GMAW Process 5th Weld pass	230 Amps.	27 Volts.	24 cm/min/
Gas flow rate for GTAW and GMAW was 15l/min and 20 L/min respectively.				

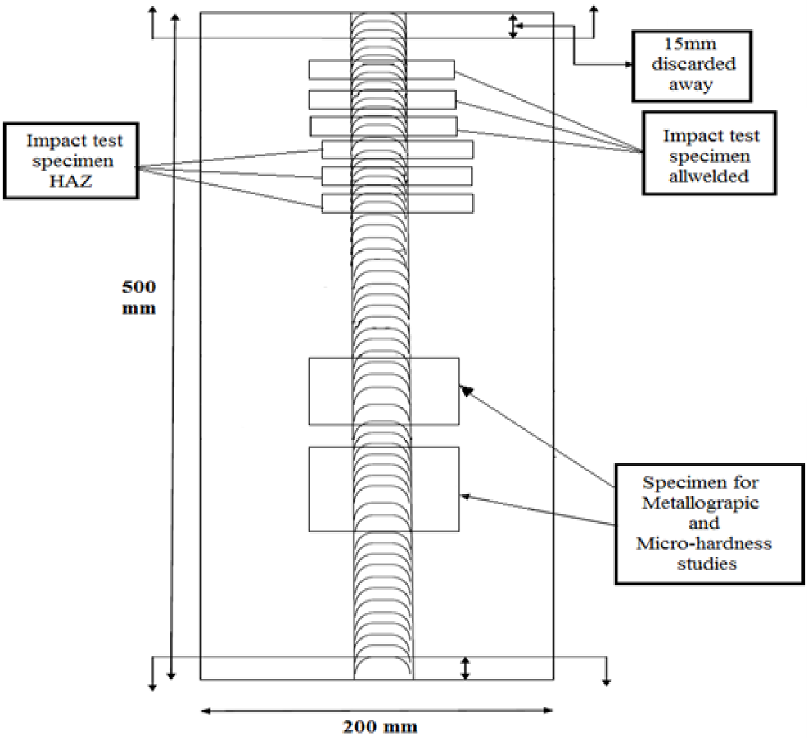

Figure 2: Schematic illustration of the specimen sampling plan from the butt welded joints

Impact toughness testing of welds

The Charpy specimens were tested on a pendulum impact testing machine of 300 J capacity, to evaluate for their impact toughness. Two testing temperatures viz. room and cryogenic were used for testing.

RESULTS AND DISCUSSION

The results of the Charpy V notch testing of different specimens are shown in Table 4 and the same are graphically shown in Fig. 3 to 6 for different weld zones and different testing temperatures.

In the as welded condition 5-pass welds showed better impact performance than the 3-pass welds. A loss of impact toughness was recorded when testing temperature was cryogenic. Further it was observed that all the welds showed an appreciable decrease in their CVN values under the aging conditions used. Higher aging time resulted into greater loss of impact toughness which could be attributed to the formation of different intermetallic precipitates which usually deteriorate the toughness of these welds. Compared with the weld metal, the respective HAZs of these joints showed relatively lesser toughness which could be attributed to two factors, i.e. firstly HAZ has a tendency of undergoing grain coarsening and secondly the extent of carbide precipitation is more in this zone, which consequentially leads to poor HAZ toughness of all the joints under all the aging as well as testing conditions.

Table 4: Impact toughness testing results of different welds

Sr. No.	Specimen code	Notch location, aging condition and testing condition	CVN (Joules)
3-pass weld	WM_3T_1	Weld metal (As welded)/ RT	224
	WM_3T_2	Weld metal (750°C/2 hours)/ RT	168
	WM_3T_3	Weld metal (750°C/12 hours)/ RT	124
	WM_3T_4	Weld metal (As welded)/CT	194
	WM_3T_5	Weld metal (750°C/2 hours)/ CT	132
	WM_3T_6	Weld metal (750°C/12 hours)/ CT	84
	HAZ_3T_1	HAZ (As welded)/ RT	138
	HAZ_3T_2	HAZ (750°C/2 hours)/ RT	129
	HAZ_3T_3	HAZ (750°C/12 hours)/ RT	114
	HAZ_3T_4	HAZ (As welded) CT	118
	HAZ_3T_5	HAZ (750°C/2 hours)/ CT	112
	HAZ_3T_6	HAZ (750°C/12 hours)/ CT	70
5-pass weld	WM_5T_1	Weld metal (As welded) /RT	242
	WM_5T_2	Weld metal (750°C/2 hours RT	158
	WM_5-T_3	Weld metal (750°C/12 hours)/ RT	134
	WM_5T_4	Weld metal (As welded) CT	210
	WM_5T_5	Weld metal (750°C/2 hours)/ CT	124
	HAZ_5T_6	Weld metal (750°C/12 hours)/ CT	92
	HAZ_5T_1	HAZ (As welded) /RT	147
	HAZ_5T_2	HAZ (750°C/2 hours)/ RT	133
	HAZ_5T_3	HAZ (750°C/12 hours)/ RT	120
	HAZ_5T_4	HAZ (As welded) CT	120
	WM_5T_5	HAZ (750°C/2 hours)/ CT	121
	HAZ_5T_6	HAZ (750°C/12 hours)/ CT	82

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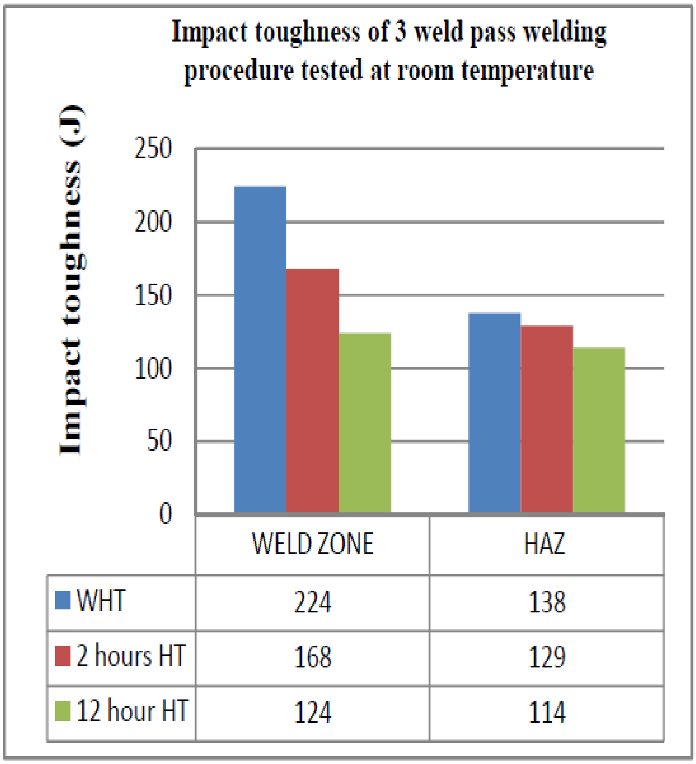

Figure 3: Impact toughness of weld metal and HAZ for the 3-weld pass welded plates tested at room temperature

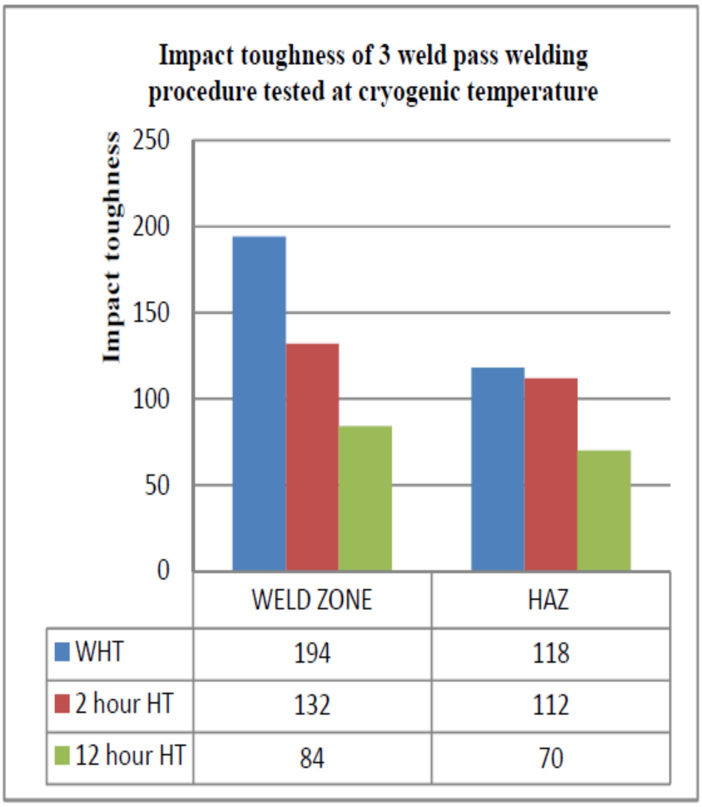

Figure 4: Impact toughness of weld metal and HAZ for the 3-weld pass welded plates tested at cryogenic temperature

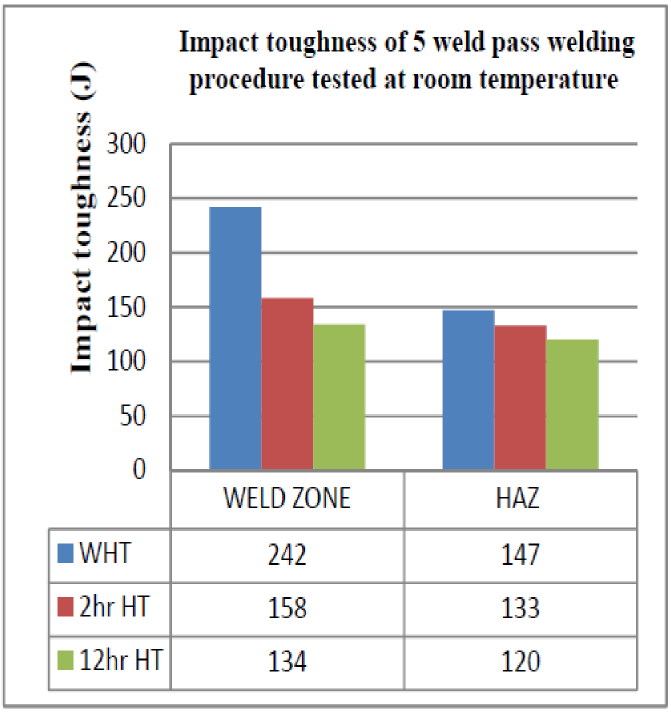

Figure 5: Impact toughness of weld metal and HAZ for the 5-weld pass welded plates tested at room temperature

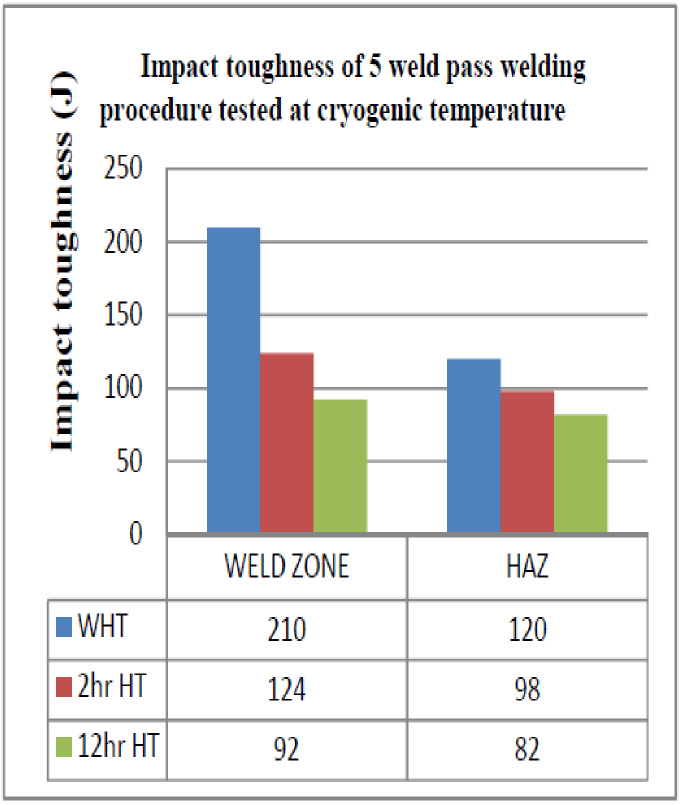

Figure 6: Impact toughness of weld metal and HAZ for the 5-weld pass welded plates tested at cryogenic temperature

CONCLUSIONS

Based upon the following work the following conclusions were drawn:-

1. Five weld pass technique resulted into higher impact toughness than the three weld pass technique in the as-welded condition.
2. Thermal aging resulted into loss of toughness in both the welds.
3. Aging condition of 750°C/12 hours resulted into higher loss of impact toughness as compared to 750°C/2 hours condition.
4. Weld metal in both the cases showed higher impact toughness as compared to the HAZ of these welds under all aging conditions.
5. Loss of toughness was more when testing temperature was cryogenic.
6. Five pass welding technique proved better in terms of imparting higher impact toughness to AISI 316L welded joints and thus can be adopted as a part of welding procedure specifications for such fabrications.

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