

Evaluation the Mechanical Behavior of SS 304L Welding Joints Designed and Fabricated According to ASME Section IX for Cryogenic Applications of Green Energy

Abobakr Alsufyani*

Department of Industrial Engineering, King Saud University, Riyadh, Saudi Arabia

*Correspondence: Abobakr Alsufyani, Department of Industrial Engineering, King Saud University, Riyadh, Saudi Arabia, E-mail: 437106969@student.ksu.edu.sa; DOI: <https://doi.org/10.56147/aaiet.1.6.98>

Citation: Alsufyani A (2025) Evaluation the Mechanical Behavior of SS 304L Welding Joints Designed and Fabricated According to ASME Section IX for Cryogenic Applications of Green Energy. J Adv Arti Int Eng & Techn 1: 98.

Abstract

The strength and toughness required for the weld metal differs greatly depending upon the application for which the structure is employed and according to the type of steel and welding materials, In this study, an austenitic stainless-steel pipe, type A304L was welded with gas tungsten arc with a wall thickness of (10) schedule, Low-temperature Charpy V-Notch (CVN) impact tests were performed to investigate the effect of low temperatures on the fracture toughness of the Welded Zone (WZ), Heat-Affected Zone (HAZ) and Base Metal (BM) of pipe. For design and safety reasons, it is necessary to investigate the low-temperature impact properties of weld metals, because weld metals have higher susceptibility to embrittlement than their counterpart base metals. The mechanical characteristics of SS304L weldments were evaluated based on tensile, Charpy impact and hardness of the WJ and BM have been measured. The conclusions from this study are summarized as follows: Mechanical tests are carried out on cryogenic temperature to check the weld behavior of stainless steel 304L under cryogenic condition of hydrogen storage units of green energy. The weld joints were successfully produced without weld defects such as cracks or blowholes. The yield strength and fracture toughness for all specimens satisfy the structural design criteria ASME and ASTM.

Keywords: SS304L; Welding joint; Cryogenic application; Toughness; Tensile; Mechanical behavior; Metallic behavior; Hydrogen; Cryogenic condition; Green energy

Received date: October 28, 2025; Accepted date: November 03, 2025; Published date: November 18, 2025

Introduction

Austenitic Stainless Steels (ASS) are used in many applications where they are susceptible to stress corrosion cracking such as nuclear power and oil and gas industries [1]. Also, widely used by the fabrication industry owing to their excellent high temperature and corrosion resistance properties. Some of the special applications of these steels include their use as nuclear structural material for reactor coolant piping, valve bodies, vessel internals, chemical and process industries, dairy industries, petrochemical industries *etc.* Out of 300 series grades of these steels type 304 SS is extensively used in industries due to its superior low temperature toughness and corrosion resistance. One of the typical applications of type 304 SS include storing

and transportation of Liquefied Natural Gas (LNG), whose boiling point is - 162°C under 1 atmosphere [2].

Joining of these materials is typically conducted by arc welding processing mostly because of its high versatility in parts, components and assemblies that can be produced using this technique [3,4]. Besides these applications, more research is needed in order to fully understand the complex mechanisms that are activated during the welding process. The concept of Welding Mechanics was coined in 1993 to focus on the strong relationship between the mechanical and fracture properties of weldments [5].

In the fabrication of structures, a variety of welding processes are employed such as Submerged Arc Welding (SAW), gas Shield arc Welding and Manual Welding

(SMAW); however, depending upon the welding processes the thermal conditions differ greatly up to the time when the weld metal is formed, solidifies and is cooled. The properties will differ according to the difference in welding conditions and special without the Post Weld Heat Treatment (PWHT) even when identical welding processes and welding materials are employed. [6]. Both strength and toughness are critical properties since failure may occur through either ductile rupture or fracture. The combination is important since strength and toughness have an inverse relation to one another; an increase in strength at given temperature almost invariably leads to a decrease in fracture toughness, while there is no reliable quantitative theory of the strength- toughness relation of structural alloys [7].

For such inhomogeneous systems, measurement of the toughness alone has little meaning if it is not related to the tensile properties of the material system. It has been demonstrated that the apparent fracture toughness of the same HAZ microstructure can be changed dramatically by just changing the tensile properties in the adjacent weld metal [8].

So, if high heat input welding is used, then the HAZ can be significantly weakened due to high temperatures and cooling rates slowly. However, the requirement does not apply universally to all quenched and tempered steels, the cooling rate is a primary factor that determines the final metallurgical structure of the weld and Heat Affected Zone (HAZ). When welding quenched and tempered steels, for example, slow cooling rates (resulting from high heat inputs) can soften the material adjacent to the weld, reducing the load-carrying capacity of the connection [9]. Weldment toughness tends to deteriorate with an increase in welding heat input. It is said that this tendency is caused by the austenite grain growth at the Heat-Affected Zone (HAZ) during the welding thermal cycle [10]. Although with the increase of heat input, the impact toughness of weld zone and heat affected zone decrease, whereas the tensile strength of the weld joints does not change at all [10].

For example, in Fusion Zone (FZ), morphology solidification mainly depends on the welding process parameters (such as voltage, amperage and welding speed) and on chemical composition of material, which produces significant property variations [11-13]. Additionally, in the Heat Affected Zone (HAZ), grain growth and secondary phase precipitations could occur as a consequence of the high thermal changes, which brings out structural problems when the material is under working conditions [13,14]. The welded joints are particularly vulnerable to fatigue damage when they are under cyclic loading conditions [3]. It is well known that welded joints are the preferential sites of crack nucleation and therefore a source for the decreasing of the fatigue strength [6]. The principal factors that affect the material properties are: the stress concentrations due to the shape of welding beads, surface and sub-surface defects, microstructural changes

in HAZ and tensile residual stresses created around the weld [4]. Thus, the cracks due fatigue could nucleate and propagate in the welded joint during its service life, even at loads below the yield point. Many applications operate at sufficiently low-temperature conditions where most structural steels become very brittle and therefore, unsuitable for use in safety-critical structures. So, the materials used in the vessels or storage tanks which keep the natural gas at liquefaction temperatures need to remain ductile and crack resistant with a high level of safety.

This paper shows the study of the microstructure, mechanical behavior of welding joints using the SMAW manufacturing processes in the austenitic stainless steel AISI304L. different factors of this process were studied amperage, voltage and heat input on the welding process, the paper is organized as follows, Section 2 describes Materials and experimental design to be used, Section 3 presents the test techniques and section. 4 discusses results and the main conclusions of the paper.

The only way to enhance the mechanical properties of the welded joint by controlling the parameters of using the welding process. From the main variables of the arc welding process are the heat input and interpass temperature where the two variables control the thermal cycle of the welding process.

Materials and Experimental Design

The pipe under study in this research has a 6 “diameter with 10 schedule (thickness) wall and are made of an ASME SA 304L steel with heat No. k1086080, seamless type.

The base metal for this study was according to ASME A312 TP304L stainless steel, the chemical composition was listed in **Table 1**.

Table 1: Base metal chemical composition.

Chemical composition							
Content	C	Si	Mn	P	S	Ni	Cr
Base metal (A304L)	0.002	0.34	0.6 5	0.3 5	0.000 6	8.1 8	18.4 4

The chemical compositions of welding consumables electrode are ER308L-ESAB brand with a lot. No equal PV8468731450 and According to the American Welding Society Specification A5.9, chemical composition summarized in **Table 2**.

Table 2: Chemical composition of welding consumables.

Chemical composition							
Content	C	Si	Mn	P	S	Ni	Cr
Welding consumable	0.007	0.3	1.9	0.0 17	0.01 5	9. 9	19. 5

Size of the non-consumable for the joints investigated in this study tungsten electrode is EWTh2 (Thoriated tungsten) of 2.4 mm diameter, Nozzle size=8 mm, shielding gas flow rate of industrially pure Argon gas=20-25cf/h, with DC Polarity, electrode negative, the welding was carried out by an automatic Gas Tungsten Arc Welding (GTAW).

Experimental set up

Welding of A304L pipe (6" with schedule 10) has been done at optimized parameters like welding speed and welding current and gas flow rate upon to welder experience and qualification to make sound weld without imperfections according to acceptance criteria of the standard. The setup of TIG welding and related accessories as shown by block diagram in below **figure 1**, whereas **figure 2** show the actual set-up of TIG welding.

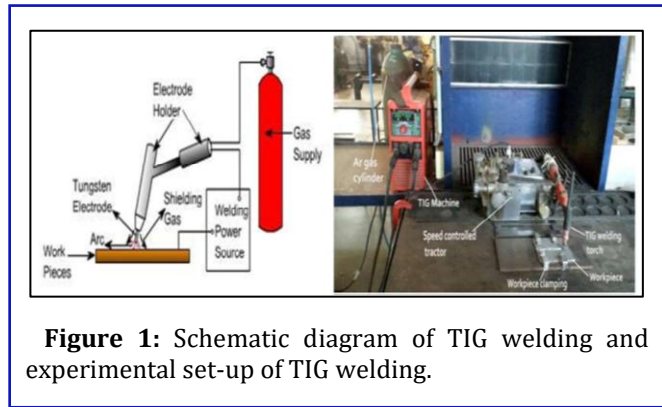


Figure 1: Schematic diagram of TIG welding and experimental set-up of TIG welding.

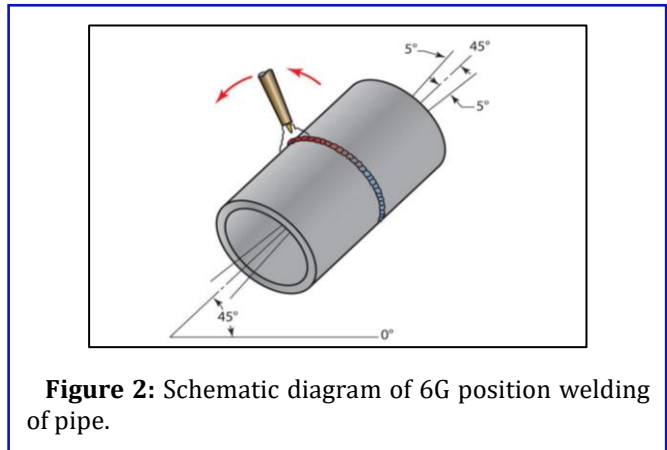


Figure 2: Schematic diagram of 6G position welding of pipe.

In this study, the stainless-steel pipe was welded by Gas Tungsten Arc Welding (GTAW), The welded joint thickness was 6 mm, GTAW is widely used in the aerospace, automotive and shipbuilding industries because it facilitates the control of welding parameters such as the heat input, travel speed and type of filler metal during welding. In the shipbuilding industry, in particular, GTAW is used with LNG membranes, pipelines and thin plates and to form joints at locations at which it is difficult to perform Shielded Metal Arc Welding (SMAW). In the present investigation, a filler metal of ER 308L (E=Electrode, R=Rod, 308L=alloy number) stainless steel with a diameter of 2.4 mm was used, because the filler metal used in GTAW should be the same as the base metal. In addition, the welding conditions and process parameters are listed in **Table 3**.

Table 3: Summary of the welding parameters.

Welding data								
Weld layer	Process	Filler metal		Current			Travel speed (mm/minute)	Heat input (KJ/mm)
		Class	(Ømm)	Polarity	Amps	Volts		
Root	GTAW	ER 308 L	2.4	DCEN	78-88	8.2-9.8	59-71	0.650-0.728
Hot pass/fill	GTAW	ER 308 L	2.4	DCEN	78-96	9-11	90-110	0.468-0.576
Capping	GTAW	ER 308 L	2.4	DCEN	78-96	9-11	90-110	0.468-0.576

The 304L austenitic stainless steel TIG welded pipe specimens are used to study stainless steel AISI/SAE 304 pipe were welded using a butt joint and 70° V-groove by the Gas Metal Arc Welding (GMAW) process.

Samples were placed in 6G position (45 degree) in three beads Figure 2, E308L electrodes were used as filler material, according to AWS 5.9 specification, specimens were labeled starting from 1 to 3 respectively for identification.

The effect of heat input on welds was investigated.

$$H_{in} = \frac{I \cdot V}{vel} \dots (1)$$

Where H_{in} is the heat input, I is the amperage, V is the

voltage and vel is the speed of the welding application. **Table 1** shows a summary of the welding parameters used in the process.

The welder was applied to qualify for 6G position pipe welding test **Figure 2** where 6g is one of the chief concerns in welding industry and primarily utilized in the fabrication of pressure equipment like; piping, boilers, pressure vessels, etc. in petrochemicals, refineries and nuclear plants. Its main purpose is, to test a welder for piping which involves the welding of the pipe joint, assembled at an angle of 45 degree. If a welder qualifies 6G position, then this mean pre-qualify to all weld types in all positions.

6G position for welding pipe is one of the chief concerns

in welding industry and primarily utilized in the fabrication of pressure equipment like; piping, boilers, pressure vessels, *etc.* in petrochemicals, refineries and nuclear plants. Its main purpose is, to test a welder for piping which involves the welding of the pipe joint, assembled at an angle of 45 degree. If a welder qualifies 6G position, he will pre-qualify to all weld types in all positions, AWS D1.1 [15].

Welding procedure

In the present work single V-groove design was used so that welding could be accomplished in two numbers of passes ensuring full penetration. Before welding all the edges were thoroughly cleaned mechanically and chemically in order to avoid any source of contamination like rust, scale, dust, oil, moisture *etc.* that could creep into the weld metal and later on, could result possibly into a weld defect. After tacking the plates together, the first weld pass was given using GTAW process with welding conditions as mentioned in Table 2 and prior to giving of the second pass an interpass temperature of around 150 C was maintained. No, preheat or post heat treatment was given to the specimens. Although the GTAW process was used in the manual mode, still utmost care was taken during the recording of the arc on time so as to facilitate calculations of welding speed for heat input calculations. It is worth mentioning here that the best welding practice available in the fabrication industry was used in the present work. It is a well-established fact that among all the welding variables in arc welding processes welding current is the most influential variable since it affects the current density and thus the melting rate of the filler as well as the base material.

After welding, the metal pipe specimens were inspected by both dye penetrant and radiographic inspection techniques, according to ASTM E165 and ASME IX respectively. Thereafter, pipes were cut in sections **Figure 3** were extracted to perform impact, tension and hardness tests respectively, according to ASTM 370 for tensile test and ASTM 384, for impact test, other pieces were discarded.

These weldments of A304L was designed for LPG storage and loading facilities project and investigation of welding performance according to American standard API and ASME section IX was applied, CVN impact test samples were fabricated in accordance with ASTM: E23, which is a standard test method for notched bar impact testing of metallic materials. Impact tests were conducted on specimens of the investigated materials with dimensions of 10 mm (W) 10 mm (T) 55 mm (L), where W is the width, T is the thickness and L is the length, at temperatures ranging from the ambient temperature to 196 According to ASTM A384, Impact test coupons were sectioned from three different regions of the weldments: the weld metal, the Heat Affected Zone (HAZ) and the parent metals, as schematically shown in **Figure 2**.

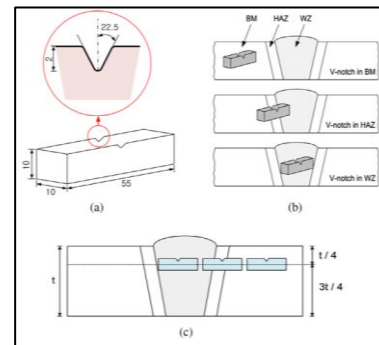


Figure 3: Schematic diagram for impact test specimens' section.

Mechanical testing and analysis

Temperature conditions of each specimen test were -196°C in liquid nitrogen, Tensile test is carried out based with ASTM E1450-92, fracture toughness was evaluated by the Charpy impact test method based on ASTM E370, Macroscopic observations of cross sections of the welded joints were made to check the robustness of welding structure and imperfection, microhardness test was performed by Vickers hardness according to ASTM E384.

Charpy-V impact test

Charpy impact tests have been done in three zones of welded joint weld metal and HAZ zones, 3 test samples for each zone according to ASME IX & ASME II-part A, SA370. The test temperature at -196°C, test specimens are cooled to the specified test temperature by immersion in an insulated bath containing a liquid that is held at the test temperature. After allowing the specimen temperature to stabilize for a few minutes it is quickly transferred to the anvil of the test machine and a pendulum hammer quickly released so that the specimen experiences an impact load behind the notch (**Figure 4**).

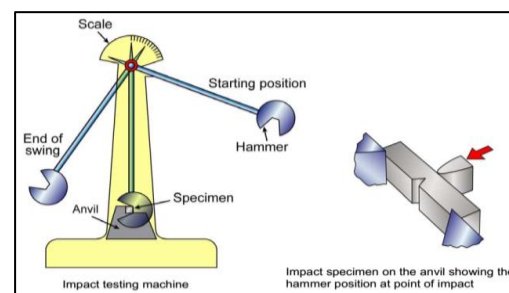


Figure 4: Schematic diagram for impact test machine.

Impact test specimens are taken in triplicate (3 specimens for each notch position) as there is always some degree of scattering in the results particularly for weldments.

Table 4 shows the Charpy-V impact test results of four

specimens, each specimen has three samples for test in the same area, welding area, HAZ and parent metal in various location, specimens NO9 where impact test was in weld center line, specimens NO 10 and NO 11, impact test was in the hazard affected zone, specimens, NO 12 where the

impact test was in the parent metal. The Charpy-V impact tests were carried out at -196 C, so these results, all weldments satisfied the requirements of BV and DNV acceptance criteria [16,17].

Table 4: Charpy-V impact test results of the weldments.

Specimen No	Notch location	Specimen size (mm)	Test temp (°C)	Impact value			
				Joules			Average
9	90	10 × 3 × 2V	-196	20	28	28	25
10	90	10 × 3 × 2V	-196	50	48	54	51
11	90	10 × 3 × 2V	-196	50	48	38	45
12	90	10 × 3 × 2V	-196	50	52	52	51

Figure 5 presents the Charpy-V impact test results for various locations of the HAZ. In the case of GTAW, WZ, exhibited the lowest impact absorbed energy, this result is attributed to the difference in heat input and controlling parameters of the welding process in addition to the specification of filler electrode was used.

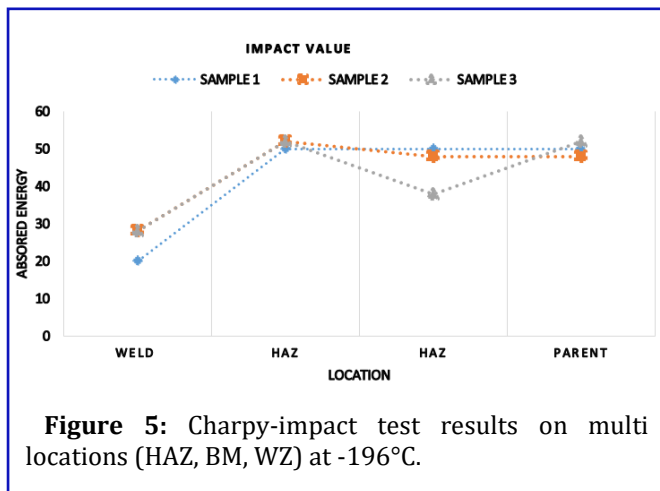


Figure 5: Charpy-impact test results on multi locations (HAZ, BM, WZ) at -196°C.

For all locations, absorbed energies of hazards affected zone were about has slightly close value with absorbed energy of parent metal, but it appears that HAZ is highly better than weld zone in terms of impact absorbed energy over all specimens.

Acceptance criteria

Each test result is recorded and an average value

calculated for each set of three tests. These values are compared with the values specified by the applicable standard to establish whether specified requirements have been met for the requirement of austenitic stainless steel weldment there are two design codes available and they describe the toughness requirement in details, (ASME B31.3) focus on lateral expansion and set the minimum design limit to ≥ 0.38 , the comparable European code (TUV) favors the Charpy impact test with the minimum allowable value has to be ≥ 32 J, depending on the applicable design code the lateral expansion and Charpy test values are the characteristic material property data for selection filler electrode for weldment.

Impact testing examination of the test specimens provides additional information about their toughness characteristics and added to the test report such lateral expansion which has been included in our report, it illustrated if toughness fracture was ductile or brittle, Lateral expansion shows the increase in width of the back of the specimen behind the notch as indicated below in figure, the larger the value the tougher the specimen which has high ductility, Lateral expansion test conducted according to ASME IX & ASME II part A, SA370.

A specimen that exhibits extreme brittleness will show a clean break. Both halves of the specimen having a completely flat fracture face with little or no lateral expansion, a specimen that exhibits very good toughness will show only a small degree of crack extension, without fracture and a high value of lateral expansion (**Table 5**).

Table 5: Lateral expansion results.

Charpy test - ASTM A370									
	Position	Dimensions	Denomination	Test temp (°C)	Energy absorbed (Joules)			Average (Joules)	Comments
009: Weld center line	90	10 × 3 × 2V	N/A	-190	20	28	28	25	See below
010: HAZ	90	10 × 3 × 2V	N/A	-196	50	48	54	51	See below
011: HAZ	90	10 × 3 × 2V	N/A	-196	50	48	38	45	See below

012: L/T parent	90	10 × 3 × 2V	N/A	-196	50	52	52	51	See below
Item 09: Lateral expansion (mm)=0.73, 0.93, 0.69 Item 10: Lateral expansion (mm)=1.24, 1.26, 1.35 Item 11: (Retest): Lateral expansion (mm)=1.37, 1.49, 1.15 Item 12: Lateral expansion (mm)=1.23, 1.26, 1.29									

As in **Figure 6**, the Lateral test results show that there is a different relation between lateral expansion values in Weld Metal (WM), HAZ and heat input. Where the lateral expansion of the W.M zone are decreased as heat input increased, the lateral test results of HAZ zone are increased as heat input increased.

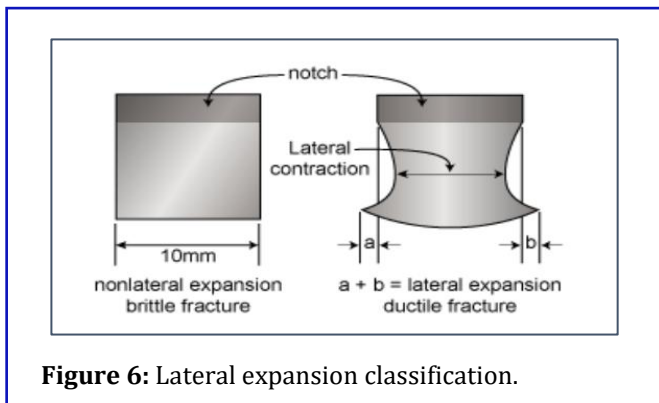


Figure 6: Lateral expansion classification.

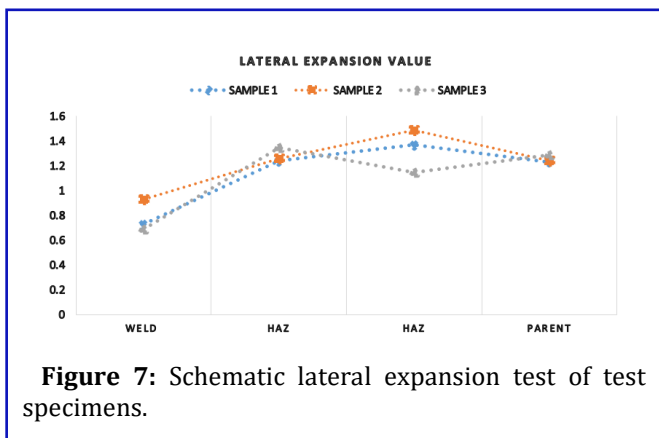


Figure 7: Schematic lateral expansion test of test specimens.

All results of lateral expansion tests show that the W.M and HAZ zones are more than the value of ASME standard required (0.38 mm) and with average 0.78, 1.28 and 1.33 mm respectively. This is meaning the Welded joint zones are high ductile and for the HAZ zone, the structure still uniform and fine grains. The WM zone are still low values comparing with the values of HAZ due to having a different chemical composition and the main alloy element is Ni So, the smallest lateral expansion as shown above in the figure was in the weld zone comparing with another zone and this due to highly concentrated of heat input during welding and also results on solidification cooling compare to HAZ and parent metal which has slightly high lateral expansion than weld zone.

Macro and microstructures

Transverse sections from butt welds are required by

the European Standards for welding procedure qualification testing and may be required for some qualification testing for assessing the quality of the welds, **Figure 2** shows the macro and microstructures of the cross-section of welded joints. There is no unusual structure such as Cr carbide (due to sensitization) was found in the Heat Affected Zone (HAZ). Besides, no cracks or harmful blowholes were found in both weld metals. GTAW weld metal has a fully austenitic structure, but a small quantity of delta ferrite was observed near the fusion line. Weld metal by EBW shows two phases' structures with austenitic and ferrite. **Figure 3** shows the weld geometry parameters together with the cross-sectional observations of bead-on-plate welds. No welding defect is found by naked eyes.

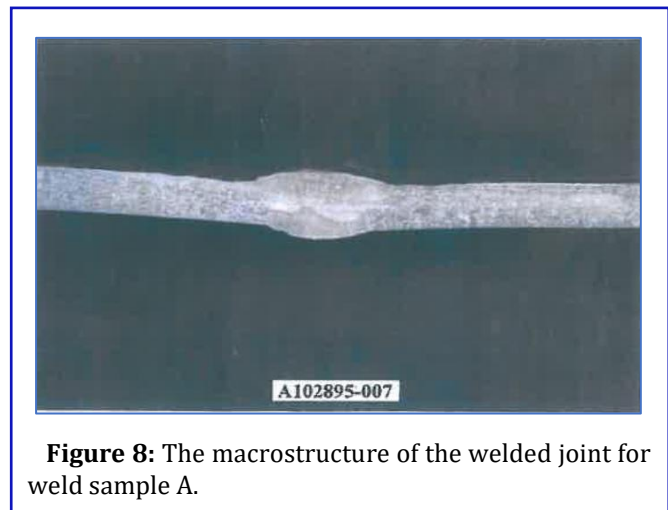


Figure 8: The macrostructure of the welded joint for weld sample A.

So specific objectives of macrostructure to detecting weld defects (macro) and detecting brittle structures, precipitates in addition to Assessing resistance toward brittle fracture, cold cracking and corrosion sensitivity, the macrograph reveals complete fusion between flanges of metal and filler electrode and it is free from cracks. A clear transition between buttering and the weld metal is visible.

Microhardness testing

Because hardness is a significant parameter for the assessment of cold cracking resistance, the strength, ductility and toughness, therefore the hardness of the BM, HAZ and WM were determined using a micro-hardness tester with a load of 10Kgf, micro-hardness measurements were made in a straight line on the middle of the cross-section to cover the complete WM, HAZ and a part of the BM. **Figure 9** shows the configuration of the weldment cross-section on which the hardness measurement was conducted.

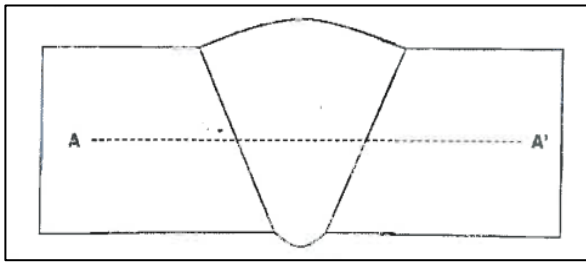


Figure 9: Schematic of weldment cross-section and hardness measurement.

Hardness measurements were carried out at different locations of the weldment along contour line A-A, the average weld hardness was found to be 114, 122, 124, 124 and 123 HV, 10 kg load was applied to the cross section of the weld on various point of parent metal, weld zone and hazard affected zone respectively, there was not much variation observed in the hardness profile. The peak hardness value at the weld zone was observed to be 172 HV.

The hardness profiles are presented in **Table 6**. There is an obvious difference between the three samples.

Table 6: Hardness measurement results.

Position	Spacing	A-A
Parent	2.0	148
Parent	2.0	151
Parent	2.0	155
HAZ	0.5	165
HAZ	0.5	163
HAZ	0.5	162
Weld	Equal	162
Weld	Equal	165
Weld	Equal	172
HAZ	0.5	164
HAZ	0.5	164
HAZ	0.5	170
Parent	2.0	168
Parent	2.0	164
Parent	2.0	163

In both samples, the average hardness of parent metal is slightly lower than that of weld zone and hazard affected zone, which can be attributed to the difference of mixing ratio of base metal and filler metal., in addition to welding parameters and amount of total heat input affected to this **(Figure 10)**.

Table 7: Tensile test results.

Specimen no.	Width (mm)	Thickness (mm)	Area (mm)	Ultimate total load (KN)	Ultimate unit stress (N/mm ²)	Type of failure & location
001	18.90	3.50	66.15	32.80	496	Parent material
002	19.00	3.40	64.60	34.90	540	Weld

It was seen the fractures took place from the gauge length in the first sample where it recorded 496 N/mm as ultimate stress with applicable load equal to 32.80 KN, But

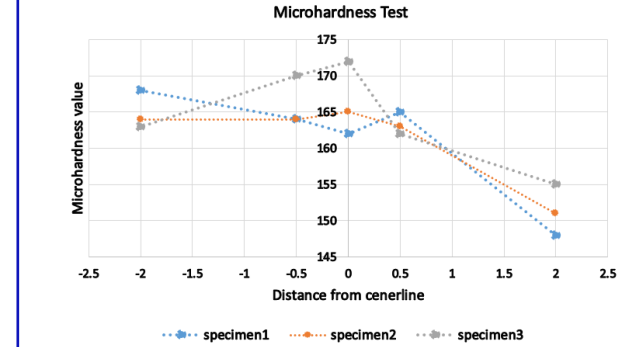


Figure 10: Schematic hardness results of welding joint.

In general, it is observed from these microhardness studies that hardness follows an increasing trend in the order of welding zone, HAZ, but slightly low microhardness value on the unaffected base metal and fusion boundary for all the joints made.

Tensile test

Tensile tests have been applied for 2 samples of the welded joint. The test conducted according to the requirements of ASME IX (32) & ASME II-part A, SA 370 (30) at room temperature and the samples shape with dimensions according to ASTM E08 as shown in **Figure 11**.

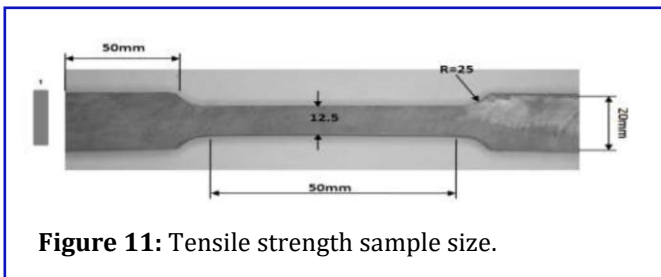


Figure 11: Tensile strength sample size.

The transverse tensile properties of weldment made using the specific welding conditions have been evaluated, two specimens have been tested and the average tensile strength is obtained to ensure repeatability, a special care is taken to have the weld zone in the middle of the tensile test samples and the weld section is kept vertical to longitudinal axis of the specimen, tensile test fracture specimens of as received base metal and TIG weldments results are shown in **table 7**.

the second sample was failed from weld area and has the maximum value of tensile strength than the first sample, it recorded 540 k/mm with maximum load equal 34.90 KN

so, this indicated that the TIG weld metal possess higher strength than that of the as-received base metal, but some of welding parameters was need to be optimize during welding such heat input because it is the key role which affected the ductility, so all both two sample in the range acceptance of minimum allowable stress, tensile properties such as Yield Strength (YS), Ultimate Tensile Strength (UTS) and tensile strain (%) of the as-received base metal and the TIG weldments are mentioned in Table 7. only UTS was considered for the comparison purpose in case of non-standard samples tensile test results [15].

Conclusions

In this study, an austenitic stainless-steel pipe, type A304L was welded with gas tungsten arc with a wall thickness of 10 schedule, Low-temperature Charpy V-Notch (CVN) impact tests were performed to investigate the effect of low temperatures on the fracture toughness of the Welded Zone (WZ), Heat-Affected Zone (HAZ) and Base Metal (BM) of pipe, therefore For design and safety reasons, it is necessary to investigate the low-temperature impact properties of weld metals, because weld metals have higher susceptibility to embrittlement than their counterpart base metals.

The mechanical characteristics of SS304L weldments were evaluated based on tensile, Charpy-V impact and hardness of the WJ and BM have been measured. the conclusions from this study are summarized as follows: Mechanical tests are carried out on cryogenic temperature to check the weld qualification of stainless steel 304L used in the LPG project. The weld joints were successfully produced without weld defects such as cracks or blowholes. The yield strength and fracture toughness for all specimens satisfy the structural design criteria of ASME and ASTM. Especially, weld joint by GTAW has good fracture toughness due to high nickel contents, CVN impact tests were conducted by varying the notch locations (BM, HAZ and WZ) on machined pieces of pipeline samples.

So, this acceptance value of mechanical properties provides evidence that this welding joint has high capabilities and grantees to withstand cryogenic condition with the durability and designed life cycle, also welding craftsman has high capabilities and grantees to weld with legality and authority to make sound weld according to procedures of standard ASME IX.

References

1. Jackson HF, San Marchi C, Balch DK, Somerday BP (2013) Effect of low temperature on hydrogen-assisted crack propagation in 304L/308L austenitic stainless steel fusion welds. *Corros Sci* 77: 210-221.
2. Kumar S, Shahi AS (2011) Effect of heat input on the microstructure and mechanical properties of gas tungsten arc welded AISI 304 stainless steel joints. *Mater Des* 32: 3617-3623.
3. Stephens RI, Fatemi A, Stephens RR, Fuchs HO (2000) *Metal fatigue in engineering*. John Wiley & Sons: New York.
4. Lassen T, Recho N (2013) *Fatigue life analyses of welded structures: Flaws*. John Wiley & Sons: New York.
5. Toyoda M (1997) Constraint effect-how to link between structural integrity assessment and fracture toughness evaluation. *J Offshore Mech Arct Eng* 119: 125-133.
6. Ohkita S (2003) Control of strength and toughness in weld metals. *Weld Int* 17: 693-698.
7. Thaulow C, Hauge M, Zhang ZL, Ranestad Ø, Fattorini F (1999) On the interrelationship between fracture toughness and material mismatch for cracks located at the fusion line of weldments. *Eng Fract Mech* 64: 367-382.
8. Thaulow C (1994) Fracture property of HAZ-notched weld joint with mechanical mismatching-Part II: Effect of local mechanical mismatching on fracture initiation in steel weldment. *Proc Int Symp Mis-Matching Welds, ESIS Publ* 17: 417-432.
9. Funderburk RS (1999) A look at input. *Weld Innov* 16: 359.
10. Juan W, Yajiang L, Peng L (2003) Effect of weld heat input on toughness and structure of HAZ of a new super-high strength steel. *Bull Mater Sci* 26: 301-305.
11. Murakami Y (2002) *Metal fatigue: Effects of small defects and nonmetallic inclusions*. Elsevier, Amsterdam.
12. Oh J, Kim NJ, Lee S, Lee EW (2003) Correlation of fatigue properties and microstructure in investment cast Ti-6Al-4V welds. *Mater Sci Eng A* 340: 232-242.
13. Lakshminarayanan AK, Shanmugam K, Balasubramanian V (2009) Effect of welding processes on tensile, impact, hardness and microstructure of joints made of AISI 409M FSS base metal and AISI 308L ASS filler metals. *Ironmak Steelmak* 36: 75-80.
14. Messler RW Jr (2008) *Principles of welding: Processes, physics, chemistry and metallurgy*. John Wiley & Sons: New York.
15. Easterling K (2013) *Introduction to the physical metallurgy of welding*. Elsevier: Amsterdam.
16. Chizen K, Moles M (2007) Phased array for piping inspections using ASME B31.3. *ASME Conf Proc*: 1-6.
17. Blodgett OW, Funderburk RS, Miller DK, Quintana M (1999) *Fabricators' and erectors' guide to welded steel construction*. James F Lincoln Arc Weld Found: 42-44.