Effect of Filler Materials on Mechanical Properties of Shielded Metal Arc Welded AISI 316L Austenitic Stainless Steel Joints

Asad Yousaf*[1], Riffat Asim Pasha[1], Ashfaq Muhammad[2]
[1]Mechanical Engineering Department, University of Engineering and Technology, Taxila, Pakistan
[2]Mechanical Engineering Department, University of Engineering and Technology, Peshawar, Pakistan
*asadyousafmarwat@gmail.com

Abstract
Austenitic stainless steels are chromium and nickel stainless steels that are broadly utilized in most engineering industries due to their enhanced mechanical characteristics at elevated temperatures, excellent corroding resistivity in varied conditions, good weldability and ease of fabrication. Shielded metal arc welding is largely employed in most manufacturing applications because of its variability, simpleness and inside/outside feasibility. This research aims to study the effect of different filler materials over the mechanical properties of AISI 316L austenitic stainless steel joints welded through shielded metal arc welding. In this research, AISI 316L plates with 10mm thickness were joined by shielded metal arc welding using three different filler materials E308, E309 and E316L. Radiographic tests were carried out on these welded plates to conform their interior soundness (non-defectiveness). Effect of filler materials E308, E309 and E316L over the mechanical properties of the welded specimens as expressed by tensile test (yield strength, ultimate tensile strength and percent elongation), impact test and hardness test was evaluated. It was accomplished from the research that the filler material E308 demonstrated better mechanical properties than E309 and E316L filler materials and that the same could be adopted for achieving optimum mechanical properties through shielded metal arc welding.

Keywords
Austenitic stainless steels, AISI 316L, Shielded metal arc welding, Filler materials, Mechanical properties.

Introduction

AISI 316L ASS (austenitic stainless steels) are largely used in most manufacturing organizations because of their improved mechanical characteristics, excellent corroding resistivity, good weldability and ease of fabrication. These are used in fabrication of large structures, pipe work, heavy plates, different boilers, pressure and marine vessels, tanks, large ships, different types of heat exchangers, equipments of nuclear reactors, various pumps, multiple valves, fastener elements, paper/pulp based industry, oil and gas industry, petro chemical industry etc. The main constituents of AISI 316L ASS that includes chromium, molybdenum and nickel make it suitable for applications involving higher temperatures and corrosive media [1]. The only major difference between AISI 316 ASS and AISI 316L ASS is their carbon content that is 0.08% maximum in AISI 316 ASS and have similar physical, thermal and mechanical characteristics. The letter "L" in the name of AISI 316L ASS denotes a low carbon content, which helps to prevent stress corrosion cracking [1].

SMAW (shielded metal arc welding) is amongst the oldest joining procedures and is one of the most simplest and diverse methods for joining ferrous and nonferrous metals. [2]. It is additionally the most frequently used welding process in fabrication and maintenance works [3]. The SMAW process is usually known as Conventional or Manual Arc Welding, relating the fact that in most of the circumstances it is performed by a welder guiding the electrode manually. SMAW has several attributes; out of these one primary attribute is the simplicity and lightweightness of the equipment. This makes it simple to move and solid-state power sources are there which are smaller and light in weight allowing them to be manually transported to the work sites where the weld joints to be made are in restricted places or distant from heavy power supply points. Low operating cost affiliated with the SMAW is another most attractive attribute. These are just a couple of the explanations why the SMAW process features a diverse set of uses in construction, fabrication, pipeline and maintenance works. The current range used for SMAW process usually varies between 50 and 2000 Amperes and voltage between 10 and 50 Volts [3]. SMAW remains dominant due to its simplicity and variability. Engineers and welders are comfortable with the method as results of long experience with it.

Literature Survey

Bahador et al. [4] studied the effect of using three different number of filler materials over the mechanical characteristics of welded joints of two dissimilar materials. These two different materials were structural and constructional steel (low alloy carbon steel) ASTM A516 Grade 70 and AISI 316L ASS. The welding process utilized for their welding was the manual gas tungsten arc welding (GTAW) and the three welding consumables used were ER80S - Ni1, ER309L and ERNiCrMo - 3. The findings of the research work were that the specimens welded with filler material ER80S - Ni1 possesses the greatest tensile strength whereas the tensile strength of specimens welded with filler materials ER309L and ERNiCrMo - 3 was almost similar. The hardness test conducted revealed that ER80S - Ni1 welded specimen has the greatest hardness. Ertem et al. [5] studied the influence of welding electrode material type during resistance spot welding of AISI 304 ASS. The two different electrode materials used were CuCo2Be and CuCrZr. In this research work, tensile shear load bearing capacity and hardness of weldments were evaluated. Ramkumar et al. [6] studied the influence of different filler materials over the micro-structure, mechanical characteristics and corrosive behaviour of AISI 316L ASS welded joints. The welding process used for this research work was pulsed gas tungsten arc welding (PGTAW) and therefore the two different types of filler materials used were ER2553 and ERNiCr - 3. Microstructure analysis revealed the occurrence of various shapes of austenite by utilizing filler material ER2553 whereas migrated grain boundaries were formed by using filler material ERNiCr - 3. Tensile testing of specimens revealed that the strength of weldment made with filler material ER2553 was greater than with filler material ERNiCr - 3. Impact test results showed that the impact properties were greater for ER2553 welded joints. Also by studying potentiodynamic polarization curves, it was revealed that welding zone of filler material ER2553 adopted higher corrosion resistant properties as compared to filler material ERNiCr-3. Verma et al. [7] studied the influence of electrode material type over the mechanical characteristics and microstructure of AISI 316L ASS and 2205 Austeno Ferrite weldments. In this research study, the weldability, micro-structure and mechanical characteristics of welded joints of two dis-similar materials (2205 austeno - ferritic and AISI 316L ASS) were studied by utilizing SMAW process. The two different types of welding electrodes used were duplex E2209 and austenite E309L. In this research work, it was revealed that in case of welding with electrode E2209 solidification was the prime ferrite process. Whereas in welded joint of electrode E309L prime component was the ferritic weldment with austenitic matrix. At the end, it was accomplished that for the weldments made between AISI 316L ASS and 2205 Austeno Ferrite, E2209 was superior in properties. Buchely et al. [8] investigated the impact of the SMAW procedure over cyclic behaviour of AISI 308L ASS as filler material and AISI 304 as base material. The effects of three distinct types of electrode coatings that are E308L - 15, E308L - 16, and E318L premium were compared in this study. The weldments microstructure, chemical composition, ferrite no (FN), tensile and hardness tests were evaluated after welding. Using INSTRON - 8872 equipment, other fatigue experiments were also conducted. Electrodes with coating - 15 were shown to be more resistant to high-cycle fatigue than - 16 and E318L - 16 premium electrode coatings.

Materials and Experimental Procedures

Materials

In current research work, AISI 316L ASS plate is employed as a base material. Its composition and properties according to ASTM A240 and ASME SA-240 specifications are as follows;

Table 1 – Chemical Composition of AISI 316L ASS

Elements	C	Mn	P	S	Si	Cr	Ni	Mo	N	Fe
Composition [%]	0.03 max	2.0 max	0.045 max	0.03 max	0.75 max	16.0–18.0	10.0-14.0	2.0-3.0	0.1 max	Balance

Table 2 – Mechanical Properties of AISI 316L ASS

Yield Strength [MPa]	Tensile Strength [MPa]	Percent Elongation in 2 in. or 51 mm. [%]	Hardness [HRB]	Impact Toughness [J]
170	485	40.0	95 max	88 - 134

The three different types of filler materials used for joining the plates are E308, E309 and E316L. The following is a list of their chemical composition and mechanical properties;

Table 3 – Chemical Composition of Filler Materials

Filler Material (AWS)	Composition [%]			
	C	Cr	Ni	Mo
E308	0.06	20.1	9.6	-
E309	0.09	23.8	13.0	-
E316L	0.03	19.2	12.4	2.2

Table 4 – Mechanical Properties of Filler Materials

Filler Material (AWS)	Tensile Strength [1000 psi]	Elongation in 2 in. [%]
E308	90	41
E309	81	40
E316L	82	41

Welding Process

Three plates of AISI 316L ASS are finished to final dimensions of 220 mm x 190mm x 10 mm. These are then edge prepared/beveled for SMAW welding through lathe machine as shown in the following figure;

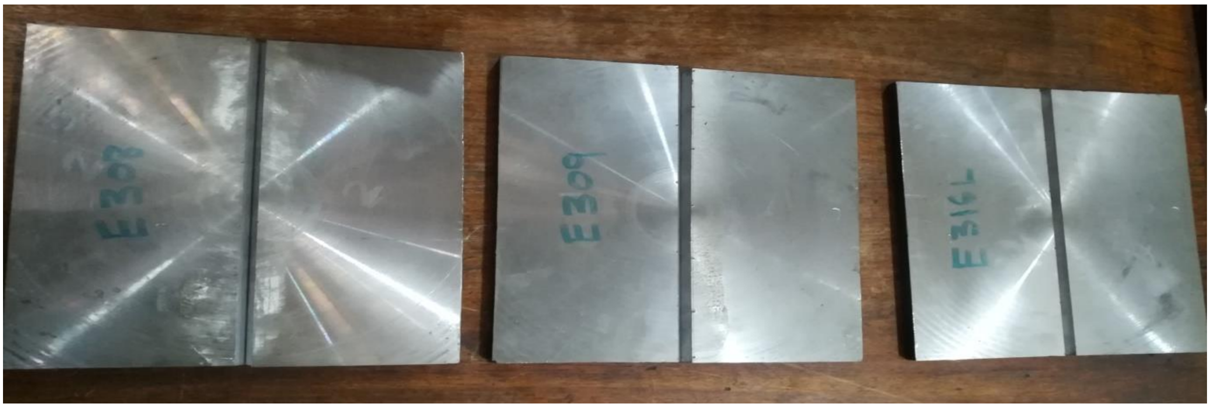

Figure 1. Edge Prepared / Bevelled AISI 316L ASS Plate For SMAW Welding

These three edge prepared/beveled plates are then SMAW welded using three different types of filler materials that are E308, E309 and E316L. The schematic of the welded plates is shown in the following figure;

Figure 2. SMAW Welded AISI 316L ASS Plates Using Three Different Filler Materials

Extraction of Specimens

The samples for tensile strength, impact toughness, and hardness are prepared perpendicular to the direction of weld joint as per ASTM A370 and ASME SA-370 standards and are shown in the schematics below. Three samples for testing each mechanical property from each welded plate are extracted using electric discharge machining (EDM) machine and are tested and average value of these tests is calculated in order to minimize the possibility of error.

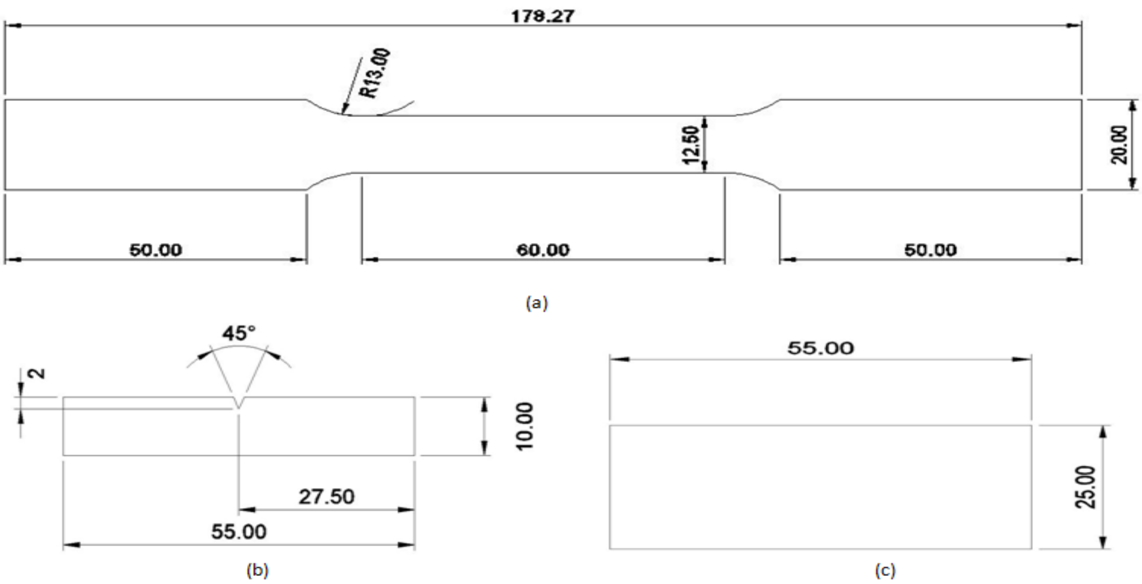

Figure 3. Schematic of (a) Tensile Specimen (b) Impact Specimen and (c) Hardness Specimen

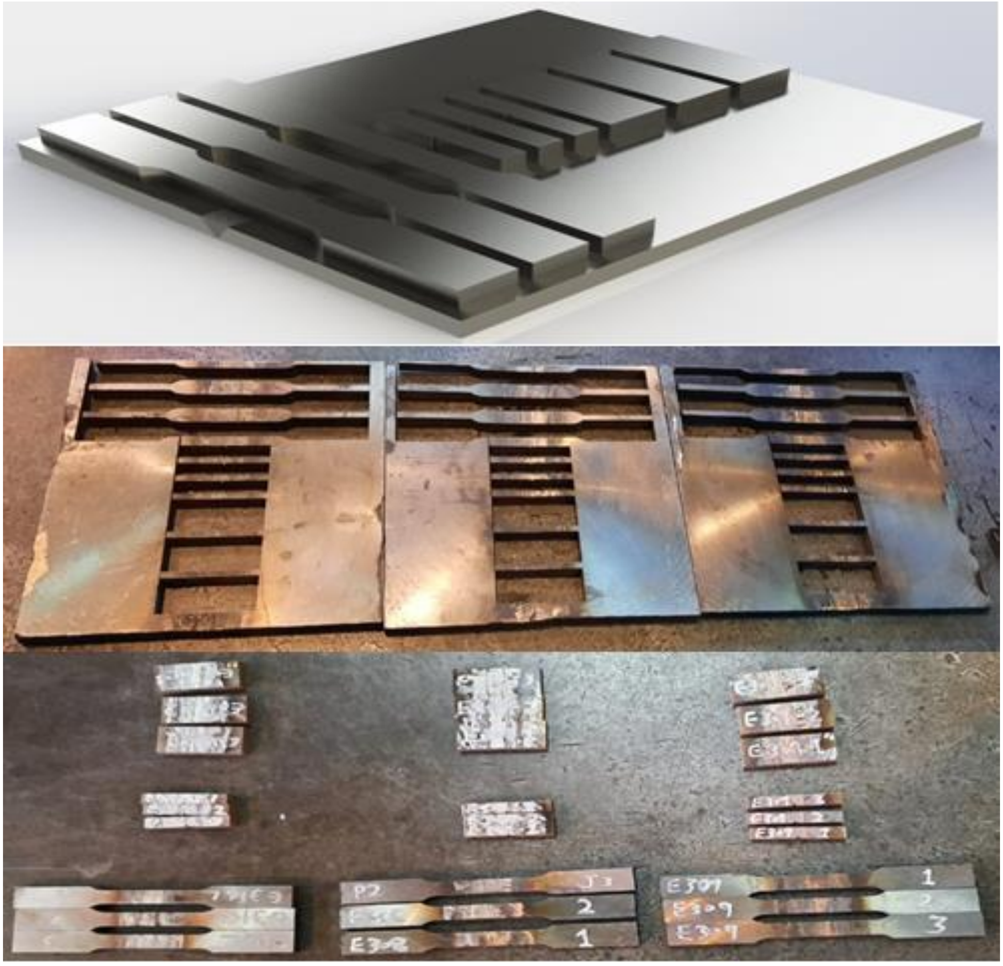

Figure 4. Specimens Extracted for Tensile, Impact and Hardness Tests

Figure 5. Physical Dimensions of Tensile, Impact and Hardness Specimens

Tensile, Impact and Hardness Testing

Tensile testing was carried out to determine yield strength, ultimate tensile strength and percentage elongation. A universal testing machine (UTM) having 30 tons capacity was used to conduct the tests in compliance with the ASTM E8 standard. The impact tests were undertaken in accordance to ASTM E23 standards. The charpy V-Notch tests data was obtained in terms of energy absorbed (Joules) and strength (Joules/cm²). These tests were performed using impact testing machine with 30/15 kgs hammers capacity. Hardness tests were carried out to determine Rockwell hardness B (HRB) at room temperature.

Figure 6. Tensile, Impact and Hardness Testing of Specimens

Results and Discussion

Tensile Properties

From tensile tests, different tensile properties that are yield strength, ultimate tensile strength and percent elongation of SMAW welded AISI 316L ASS specimens using three different types of filler materials E308, E309 and E316L, are investigated. In every case, testing of 3 samples is undertaken and their average result is listed as follows;

Table 5 – Tensile Test Results

Filler Material	Yield Strength [MPa]	Tensile Strength [MPa]	Percent Elongation in 2 in. or 50 mm. [%]
E308	396	514	26
E309	382	508	25.4
E316L	381	499	25.3

The tensile test results of SMAW welded AISI 316L ASS plates using three different filler materials are also shown by bar diagram in the following figure;

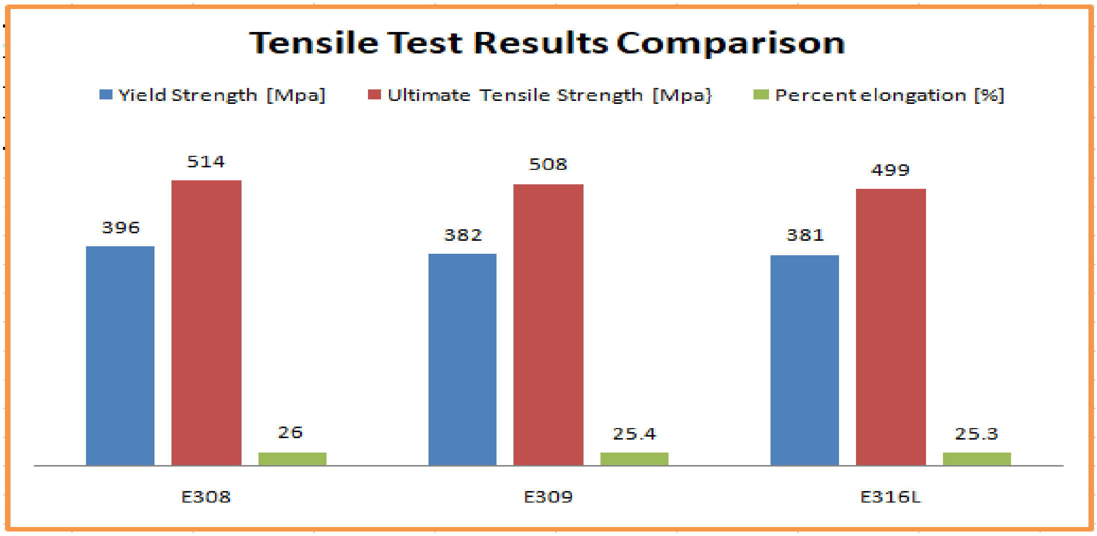

Figure 7. Tensile Test Results of SMAW Welded AISI 316L ASS Plate Using Different Filler Materials

Impact Properties

The charpy V-Notch tests of SMAW welded AISI 316L ASS specimens using three different types of filler materials E308, E309 and E316L are conducted at room temperature and fracture toughness and toughness strength are investigated. For each case, 3 tests are performed and their average value is listed as follows;

Table 6 – Impact Test Results

Filler Material	Fracture Toughness [J]	Fracture Strength [J/cm²]
E308	141.12	176.4
E309	130.34	162.925
E316L	130.83	163.5375

The charpy V-Notch test results of SMAW welded AISI 316L ASS plates using three different filler materials are also shown by bar diagram in the following figure;

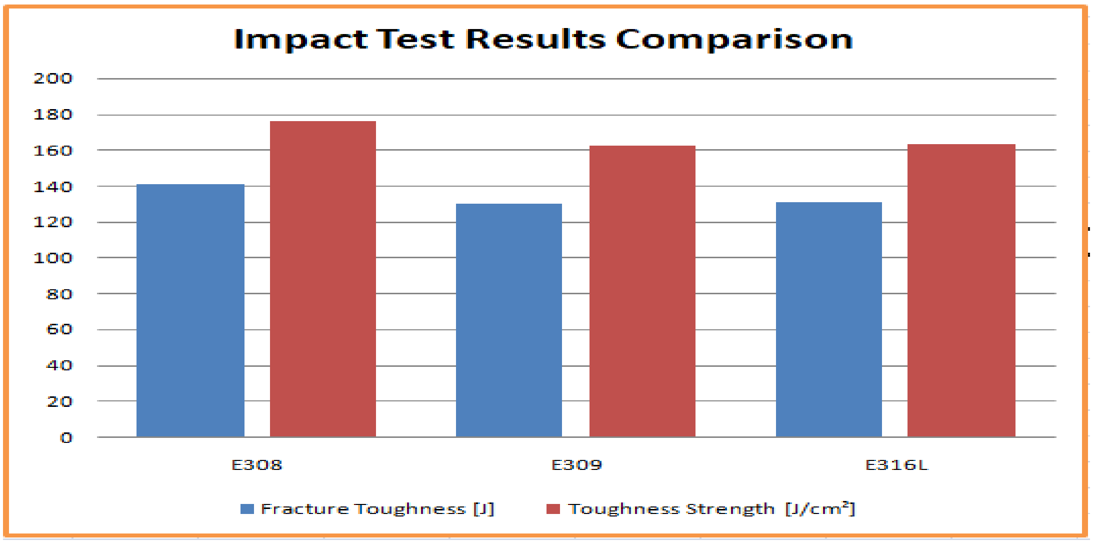

Figure 8. Impact Test Results of SMAW Welded AISI 316L ASS Plate Using Different Filler Materials

Hardness Properties

The hardness tests of SMAW welded AISI 316L ASS specimens using three different types of filler materials E308, E309 and E316L are conducted and hardness of these specimens is investigated. In every case, 3 tests are conducted and their average result is listed as follows;

Table 7 – Hardness Test Results

Filler Material	Hardness [HRB]
E308	88
E309	84
E316L	93

The hardness test results of SMAW welded AISI 316L ASS plates using three different filler materials are also shown by bar diagram in the following figure;

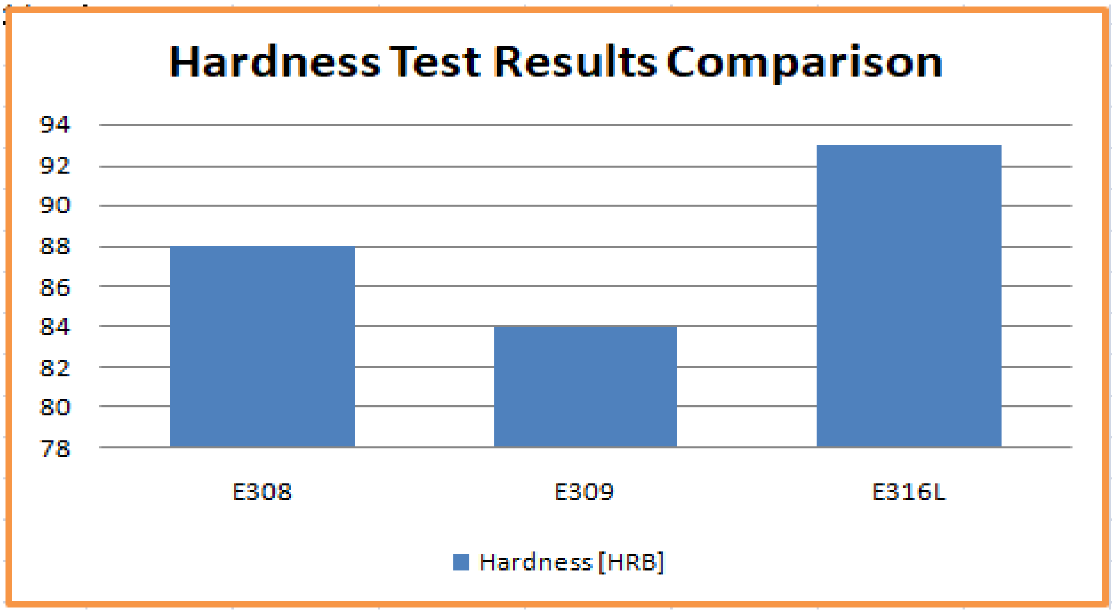

Figure 9. Hardness Test Results of SMAW Welded AISI 316L ASS Plate Using Different Filler Materials

Conclusions

In this research study, AISI 316L ASS plates are welded using E308, E309 and E316L filler materials through SMAW process. The various conclusions acquired from the experiments undertaken are presented as follows;

- The tensile properties that are yield strength, ultimate tensile strength and percent elongation of SMAW welded AISI 316L ASS are higher for E308 filler material than for E309 and E316L filler materials. Comparatively E308 joint endures 3.66% higher yield strength than E309 & 3.94% than E316L, 1.18% higher tensile strength than E309 & 3.00% than E316L and 2.36% higher percent elongation than E309 & 2.76% than E316L.
- The impact properties that are fracture toughness and fracture strength of SMAW welded AISI 316L ASS are also higher for E308 filler material than for E309 and E316L filler materials. Comparably E308 weldment shows 8.27% higher fracture toughness & fracture strength than E309 and 7.86% than E316L.
- No big difference in the tensile properties (yield strength, ultimate tensile strength and percent elongation) and impact properties (fracture toughness and fracture strength) are obtained for the weldments of both E309 and E316L filler materials by SMAW process. However, the E309 joint shows a little higher tensile values (0.26% yield strength, 1.8% tensile strength & 0.40% percent elongation) than E316L and little lower impact values (0.38% fracture toughness and fracture strength) than E316L.
- The hardness values of SMAW welded AISI 316L ASS are higher for E316L filler material, then for E308 filler material and is lowest for the E309 filler material, respectively. These are 93HRB for E316L, 88HRB for E308 and 84HRB for E309 weldments.

Nomenclature

AISI	American Iron and Steel Institute
ASS	Austenitic Stainless Steel
SMAW	Shielded Metal Arc Welding
AWS	American Welding Society
RT	Radiographic Testing
ASTM	American Society for Testing Materials
GTAW	Gas Tungsten Arc Welding
PGTAW	Pulsed Gas Tungsten Arc Welding
HRB	Rockwell Hardness B
FN	Ferrite Number
ASME	American Society of Mechanical Engineers
EDM	Electric Discharge Machining
UTM	Universal Testing Machine

References

[1] I.M.W. Ekaputra, Sudi Mungkasi, Gunawan Dwi Haryadi, Rando Tungga Dewa, and Seon-Jin Kim, The influence of welding speed conditions of GMAW on mechanical properties of 316L austenitic stainless steel, MATEC Web of Conferences 159, 02009 (2018), IJCAET & ISAMPE 2017, https://doi.org/10.1051/matecconf/201815902009.

[2] American Welding Society (AWS), Welding Handbook, 8th Edition, Volume 2, 1998.

[3] J.P. Kaushish, Manufacturing Processes, 2nd Edition, 2008.

[4] Abdollah Bahador, Esah Hamzah, Mohd Fauzi Mamat, Effect of Filler Metals on the Mechanical Properties of Dissimilar Welding of Stainless Steel 316L and Carbon Steel A516 GR 70, 75:7 (2015) 61–65 | www.jurnalteknologi.utm.my | eISSN 2180–3722.

[5] Ali Güray Ertem, Yahya Altunpak, Effect of Electrode Materials type on Resistance Spot Welding of AISI 304 Austenitic Stainless Steel (ASS) Sheets, ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.177, Volume 7 Issue XI, Nov 2019- Available at www.ijraset.com, DOI: http://doi.org/10.22214/ijraset.2019.11045.

[6] K. Devendranath Ramkumar, P. Maruthi Mohan Reddy, B. Raja Arjun, Ayush Choudhary, Anubhav Srivastava, N. Arivazhagan, Effect of Filler Metals on the Weldability and Mechanical Properties of Multi-pass PCGTA Weldments of AISI 316L, Journal of Material Engineering and Performance (JMEPEG), 2015, DOI: 10.1007/s11665-015-1418-0.

[7] Jagesvar Verma, Ravindra Vasantrao Taiwade, Rajesh Kisni Khatirkar, Anil Kumar, A Comparative Study on the Effect of Electrode on Microstructure and Mechanical Properties of Dissimilar Welds of 2205 Austeno-Ferritic and 316L Austenitic Stainless Steel, Materials Transactions, Vol. 57, No. 4 (2016) pp. 494 to 500, ©2016 The Japan Institute of Metals and Materials.

[8] M.F. Buchely, H.A. Colorado, H.E. Jaramillo, effect of SMAW manufacturing process in high-cycle fatigue of AISI 304 base metal using AISI 308L filler metal, Journal of Manufacturing Processes (2015), http://dx.doi.org/10.1016/j.jmapro.2015.08.005.

[9] L. S. Sisira K Weerasekralage, M. S. A. Karunaratne, S. D. Pathirana, Optimization of Shielded Metal Arc Welding (SMAW) process for mild steel, Annual Sessions of IESL, pp. [841 - 847], 2019.

[10] Shashi Kumar, S., Murugan, N. & Ramachandran, K.K. Effect of friction stir welding on mechanical and microstructural properties of AISI 316L stainless steel butt joints. *Weld World* **63,** 137–150 (2019). https://doi.org/10.1007/s40194-018-0621-7.

[11] S Senthur Prabu, K Devendranath Ramkumar and N Arivazhagan, Effect of filler metals on the mechanical properties of Inconel 625 and AISI 904L dissimilar weldments using gas tungsten arc welding, S Senthur Prabu *et al* 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **263** 062072.

[12] Magudeeswaran, G., Balasubramanian, V., Reddy, G.M. *et al.* Effect of Welding Processes and Consumables on Tensile and Impact Properties of High Strength Quenched and Tempered Steel Joints. *J. Iron Steel Res. Int.* **15,** 87–94 (2008). https://doi.org/10.1016/S1006-706X(08)60273-3.

[13] A. K. Lakshminarayanan, K. Shanmugam & V. Balasubramanian (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, Ironmaking & Steelmaking, 36:1, 75-80, DOI: 10.1179/174328108X378224.

[14] Shang, Y., Yuan, Y., Li, D. *et al.* Effects of scanning speed on in vitro biocompatibility of 316L stainless steel parts elaborated by selective laser melting. *Int J Adv Manuf Technol* **92,** 4379–4385 (2017). https://doi.org/10.1007/s00170-017-0525-5.

[15] Moi Subhas Chandra, Pal Pradip Kumar, Bandyopadhyay Asish, Rudrapati Ramesh, Determination of Tungsten Inert Gas Welding Input Parameters to Attain Maximum Tensile Strength of 316l Austenitic Stainless Steel, Journal of Mechanical Engineering – Strojnícky časopis, Vol 68 (2018), No 3, 231 – 248, DOI: https://doi.org/10.2478/scjme-2018-0037.

[16] Amudarasan, N. V., et al. “Mechanical Properties of AISI 316L Austenitic Stainless Steels Welded by GTAW.” Advanced Materials Research, vol. 849, Trans Tech Publications, Ltd., Nov. 2013, pp. 50–57. Crossref, doi:10.4028/www.scientific.net/amr.849.50.

[17] Haetham G. Mohammed, Turnad L. Ginta, Mazli Mustapha, the investigation of microstructure and mechanical properties of resistance spot welded AISI 316L austenitic stainless steel, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2020.07.258 (2020).

[18] Saxena, A., Kumaraswamy, A., Madhusudhan Reddy, G., & Madhu, V. (2018). Influence of welding consumables on tensile and impact properties of multi-pass SMAW Armox 500T steel joints vis-a-vis base metal. *Defence Technology*, *14*(3), 188–195. https://doi.org/10.1016/j.dt.2018.01.005.

[19] A Designers’ Hand Book Series N 9002, Welding of Stainless Steels and Other Joining Methods, Distributed By Nickel Development Institute, Produced By American Iron And Steel Institute.