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Assessment of Tensile Strength, Hardness and Impact Toughness of API 5L Grade X65 Carbon Steel Pipe Welded Joints at the HAZ using TIG and SMAW Techniques

Stanley Okiy[1*] and Benjamin Ufuoma Oreko[2]
[1]Department of Welding Engineering and Offshore Technology,
Petroleum Training Institute Effurun, Delta State, Nigeria
[2]Deptartment of Mechanical Engineering,
Federal University of Petroleum Resources, Effurun, Delta State, Nigeria

ABSTRACT

This study examines the mechanical properties namely tensile strength, hardness and impact toughness of API 5L grade X65 carbon steel pipe at the Heat Affected Zone (HAZ) using Tungsten Inert Gas (TIG) and Shielded Metal Arc Welding (SMAW) processes. The welding parameters considered in this study were Voltage (V), Current (A) and Travel/Welding Speed (cm/min). The results obtained show that TIG welded joints at the HAZ had an optimum value for tensile strength, hardness and impact toughness of 5.879×10^5 kN/m^2, BHN 198.6 and 160 J/m^2, respectively. In contrast, the optimum for SMAW welded joints at the HAZ shows the tensile strength, hardness and impact toughness of 5.2235×10^5 kN/m^2, BHN 196.7 and 134 J/m^2, respectively. Equally too, Taguchi analysis ranked travel/welding speed, current and voltage as first, second and third, respectively, to be considered as significant to achieve optimum value at the HAZ for UTS when using TIG and SMAW techniques whereas, for hardness and impact toughness, consideration could be given to voltage first, closely followed by current and travel speed, respectively. Hence, the welding parameters considered in this study could influence the properties of API 5L grade X65 carbon steel pipe at the heat-affected zone.

Keywords: Carbon Steel pipe, TIG, SMAW, Heat Affected Zone, Taguchi Design

INTRODUCTION

Investigating the influence of these parameters on the performance of carbon steel pipe welded joints in the HAZ is necessary for developing optimized welding procedures and quality control measures. The study aims to evaluate the performance of carbon steel pipe welded joints at the heat-affected zone. Dehghani et.al. (2013) investigated the effects of friction stir welding parameters on intermetallic and defect formation in joining aluminum alloy to mild steel using the friction stir welding (FSW) technique. The effects of various FSW parameters such as tool traverse speed, plunge depth, tilt angle and tool pin geometry on the formation of intermetallic compounds (IMCs), tunnel formation and tensile strength of the joints were investigated. They observed that at low welding speeds due to the formation of thick IMCs in the weld zone, the tensile strength of joints was feeble and at a higher welding speed and lower tool plunge depth, the joint strength decreased due to lack of bonding between aluminum and steel. Bjørneklett et al. (1999) studied the use of process modelling techniques to understand the sequence of reactions that occur during welding and the natural ageing of Al-Zn-Mg extrusions and their model indicated that particle dissolution is the main factor contributing to the strength loss during welding. Hayat (2011) investigated the effects of the welding current on heat input, nugget geometry, and the mechanical and

* Corresponding Author

fractural properties of resistance spot welding on Mg/Al dissimilar materials and examined the nugget geometries of joined specimens using SEM and EDS for analysis. He found that the increase in the weld current and duration resulted in an increase in the nugget size and the weld strength and that the tensile load bearing capacity (TLBC) increased up to 29 kA of the weld current value. Kumar et al. (2017) investigated the impact toughness value of steel before and after post-weld heat treatment (PWHT) with three different soaking temperatures. using the Submerged Arc Welding (SAW) process. They observed significant improvement in impact toughness at 620°C of soaking temperature and decreased tensile strength. Cico et al. (2011) studied the effect of welding parameters of manual arc welding and gas metal on the microstructure of mild steel weldments. Their results indicated that welding parameters could affect the grain size of weldments. Fathi et al. (2019) compared the properties of tensile strength, impact energy, and micro hardness of a mild steel weldments using shielded metal arc welding (SMAW) and oxy-acetylene (OAW) welding techniques. The SMAW weldments had a better micro hardness and impact toughness compared to OAW weldments, while the OAW weldments had a better tensile strength. Al-Saraireh (2018) performed an experimental investigation on low carbon steel weldments by studying the effect of welding current and voltage on the hardness, impact toughness. yield stress, and ultimate strength of the material. He observed that increasing the welding current would lead to increase in the grain size at the welding zone and reduced the mechanical properties of the welding joints. Satyam and Sarmah (2014) studied the change of hardness, impact strength, tensile strength and microstructure on mild steel at various process parameters. They found that there was an increase in hardness and little decrease in impact and tensile strength as the current increases as well as the microstructure changed with the current increment. Srinivasan et.al (2011) examined the feasibility of joining AZ31B magnesium metal matrix composite by friction welding. They evaluated the integrity of the joints by optical microscopy, mechanical properties of the joints by tension tests microhardness tests and efficiencies of the joints using statistical analysis. They found that as the friction pressure and forging pressure increased, the joint efficiency increased. Also, as the friction time increased, the efficiency of the joint decreased. The application of friction welding and other techniques to steel to evaluate the properties and microstructural characteristics has been studied (Alves et al 2010; Fukumoto et al., 1999; Li et al., 2020; Jin, et al 2019; Kumar, et al 2021; Mullo, et al 202; Selvaraj, et al 2023; Li et al., 2016; Arunkumar, et al 2012; Mohanta and Senapati, 2018, Kainth et al., 2018; Łukaszewicz,2018; Fathi, et al., 2019). From the literature, the performance and properties of API 5L Grade X65 carbon steel pipe welded joints at the heat-affected zone have rarely been studied. API 5L X65 pipe is also called ISO 3183 L450 pipe, it is a high-level grade pipe in API 5L (ISO 3183) specifications, used for the oil and gas Industry for the transmissions or transportation of fluid. Joining such pipes in the field is one of the common processes required during the installation of the pipelines. The welding process parameters, such as heat input, Welding Voltage, welding Current, Welding speed, welding technique, and preheating/post-weld heat treatment, could significantly affect the microstructure and mechanical properties of Steels at the HAZ. Therefore, this work attempts to examine the mechanical properties namely Tensile strength, Hardness and Impact toughness of API 5L Grade X65 carbon steel pipe at the Heat affected zone (HAZ) using Tungsten Inert Gas (TIG) and Shielded Metal Arc Welding (SMAW) processes.

METHODOLOGY

Material Used

This study was conducted at the Petroleum Training Institute Effurun, Delta State, Nigeria. The materials used were purchased at Donasulu Steel Company in Warri, Delta State Nigeria, comprised of API 5L Grade X65 carbon steel pipe and electrode E6010. The following are the equipment used for the TIG and SMAW Welding process.

i. Mild steel pipe 4" schedule 60 AP52L Grade X65 carbon steel
ii. Regulator pressure gauge 12 MPa
iii. ESAB welding machine
iv. Argon gas
v. Grinding machine
vi. Filler rod
vii. Stop watch
viii. Jig and fixture
ix. Hand file
x. Lathe machine

Methods

The butt weld joint method was used in the welding process. The ends of the pipes are bevelled to form a V-shape as shown in Figure 1. Pipe preparation and the welding procedures were done and the welding runs which includes the root pass, hot pass, filler 1, filler 2 and capping were done, to obtain a sound weld, as shown in Figure 2. Cut-off samples were prepared and machined according to the required standard for UTS, hardness and impact test. The welding parameters considered are Voltage (V), travel speed (cm/min) and current (A) for TIG and SMAW methods, respectively, as shown in Tables 1 and 2. Each sample welding parameters were slightly adjusted to evaluate its effect on the mechanical properties namely; UTS, Hardness and impact strength on the welded joints at the HAZ region.

Figure 1: Bevel Pipe prepared for welding

Figure 2: Welded of pipe

Table 1: TIG Weld for 4'' Schedule 60

Welding Parameter	Run	Sample 1 Welded Joint	Sample 2 Welded Joint	Sample 3 Welded Joint	Sample 4 Joint Welded	Sample 5 Welded Joint	Sample 6 Welded Joint
Voltage (V)	Root Pass	11.9	11.80	14.7	12.3	12.90	12.22
	Hot Pass	13.5	13.65	26.4	12.3	13.10	13.32
	Filler 1	12.4	12.50	23.9	14.9	13.20	14.20
	Filler 2	4.50	12.50	23.9	23.6	14.40	12.50
	Capping	25.40	25.40	22.3	23.7	24.10	13.20
Travel	Root Pass	3.58	3.8	4.2	5.20	4.58	12.22

Speed (cm/min)	Hot Pass	8.4	8.4	8.2	5.20	7.40	13.32
	Filler 1	6.24	6.22	6.23	6.47	14.40	14.20
	Filler 2	6.31	6.41	6.48	6.48	14.80	13.7
	Capping	23.5	6.39	6.48	5.23	23.7	23.2
Current (A)	Root Pass	141	125	141	141	151	148
	Hot Pass	154	154	125	125	186	162
	Filler 1	124	126	125	125	126	128
	Filler 2	125	126	125	125	124	127
	Capping	124	121	124	124	123	122
Electrode Type	E6010	E6010	E6010	E6010	E6010	E6010	E6010

Table 2: SMAW Weld for 4'' Schedule 60

Welding Parameter	Run	Sample 1 Welded Joint	Sample 2 Welded Joint	Sample 3 Welded Joint	Sample 4 Joint Welded	Sample 5 Welded Joint	Sample 6 Welded Joint
Voltage (V)	Root Pass	26.0	26.7	27.1	27.5	27.1	27.1
	Hot Pass	23.0	28.1	22.9	22.5	25.5	23.4
	Filler 1	21.4	22.5	23.5	24.1	23.6	24.1
	Filler 2	22.3	22.4	23.9	24.9	22.5	23.6
	Capping	21.5	23.1	23.1	23.4	23.1	24.1
Travel Speed (cm/min)	Root Pass	3.58	3.8	4.2	5.20	4.58	12.22
	Hot Pass	8.4	8.4	8.2	5.20	7.40	13.32
	Filler 1	6.24	6.22	6.23	6.47	14.40	14.20
	Filler 2	6.31	6.41	6.48	6.48	14.80	13.7
	Capping	23.5	6.39	6.48	5.23	23.7	23.2
Current (A)	Root Pass	93	92	92	92	91	94
	Hot Pass	128	131	126	120	119	121
	Filler 1	127	124	123	121	120	118
	Filler 2	126	123	126	122	121	121
	Capping	121	121	121	127	126	126
Electrode Type	E6010	E6010	E6010	E6010	E6010	E6010	E6010

Tensile and Hardness Testing

A Universal Testing machine was used to carry out the tensile and BHN hardness tests on the welded AP52L Grade X65 carbon steel, as shown in Figure 3. For the UTS test, the sample was subjected to tension loading until failure occurred, and the ultimate tensile strength was determined. Figure 4 shows the samples after the test for UTS and hardness.

Figure 3: Prepared samples before test

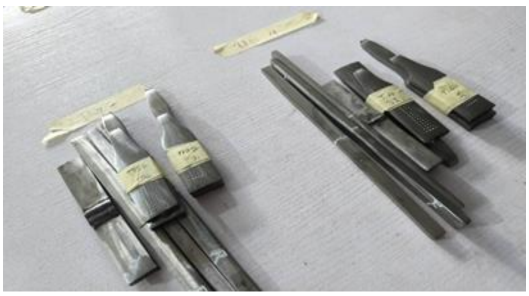

Figure 4: Sample after test

The ultimate tensile strength UTS is computed from the relation;

$$\text{UTS} = \frac{P}{A} \tag{1}$$

Where; P= Maximum Load; A = Area

The hardness readings were calculated using the equation;

$$\text{BHN} = \frac{2P}{\pi D\{D-\sqrt{(D^2-d^2)}\}} \tag{2}$$

Where, P= load applied, D=diameter of indenter, d= diameter of indentation

RESULTS AND DISCUSSION

Experiment Result and Analysis for UTS

From Figure 5, the experimental results show that SMAW joints for samples 1 to 3 had a slightly higher UTS than TIG joints at the HAZ, however, samples 5 and 6 indicated that TIG joints had a higher and better UTS with sample 6 having the highest value of 5.879×10^5 kN/m^2 at the HAZ region and the SMAW highest UTS is obtained in sample 2 with a value of 5.2235×10^5 kN/m^2. Taguchi's 'larger the better' for the TIG welding process, ranked travel Speed first, while current and voltage were ranked 2nd and 3rd, respectively, as significant to obtain the UTS optimum value, as shown in Table 3 and Figure 6, respectively. Equally too, for SMAW, the optimum response for UTS for welding parameters, Taguchi ranked travel speed as first, Current as second and voltage as third as shown in Table 4 and Figure 7.

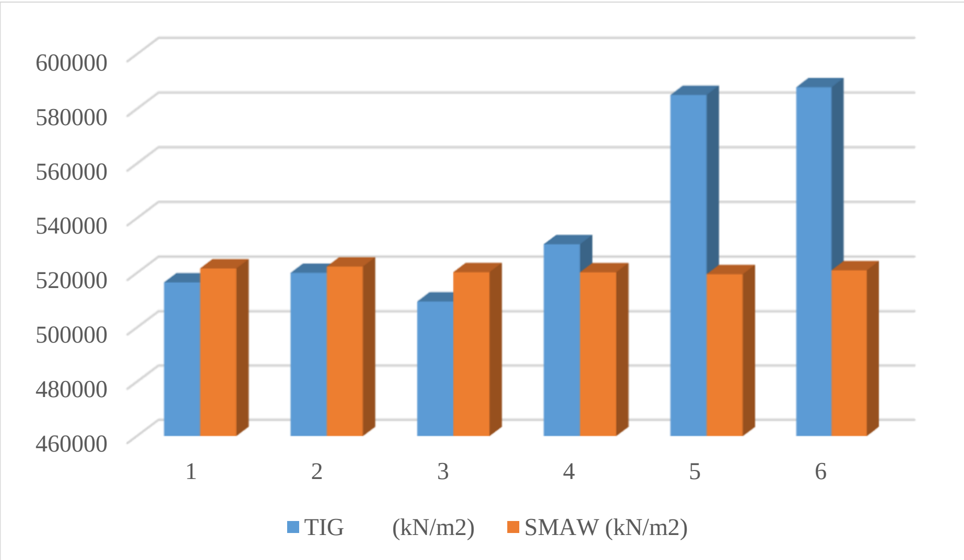

Figure 5: UTS values for TIG and SMAW with varied welding Parameters

Table 3: Response Table for Signal to Noise Ratios for UTS using TIG Welding Process

Level	Current	Voltage	Travel Speed
1	86.61	86.26	86.37
2	86.13	86.26	86.62
3	86.21	86.44	85.97
Delta	0.49	0.18	0.65
Rank	2	3	1

Note: Larger is better

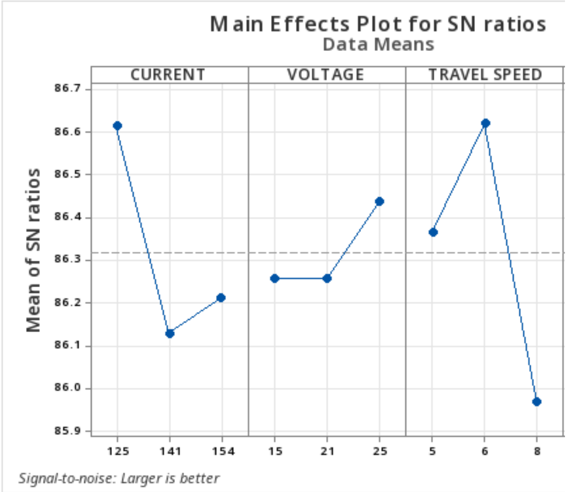

Figure 6: UTS Plot for Welding parameters vs. S/N ratio for TIG

Table 4: Response Table for Signal to Noise Ratios for UTS using SMAW Welding Process

Level	Current	Voltage	Travel Speed
1	86.66	86.46	85.92
2	86.03	85.92	86.85
3	85.81	86.11	85.73
Delta	0.85	0.54	1.12
Rank	2	3	1

Note: Larger is better

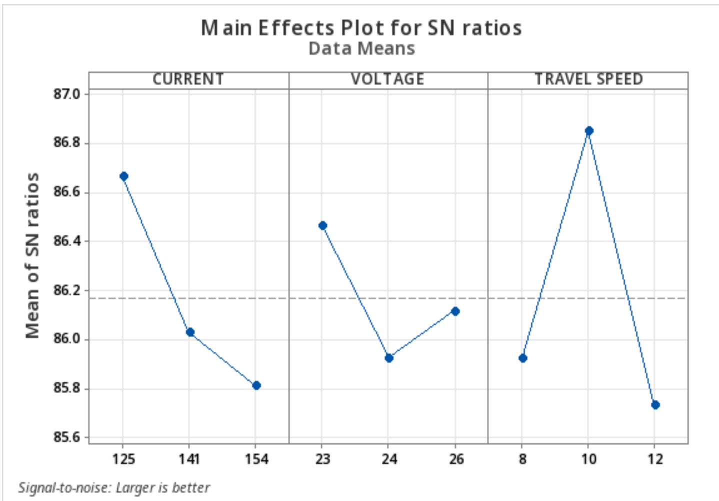

Figure 7: Plot for Welding parameters vs. S/N ratio for SMAW

Experiment Result and Analysis for Hardness

From Figure 8, the experimental results show a comparison of TIG and SMAW joints at the base metal, HAZ and weldment region, respectively. The BHN value at the HAZ was 198.6 for TIG welding which appears slightly higher as compared to SMAW with 196.7. Taguchi's ‘larger the better’ for the TIG welding process, ranked Voltage first, current and travel speed second and third, respectively, as significant to obtain the Hardness optimum value as shown in Table 5 and Figure 9. Also, for SMAW, the optimum response for hardness with respect to welding parameters, Taguchi ranked Voltage first current and travel speed for second and third, respectively as shown in Table 6 and Figure 10.

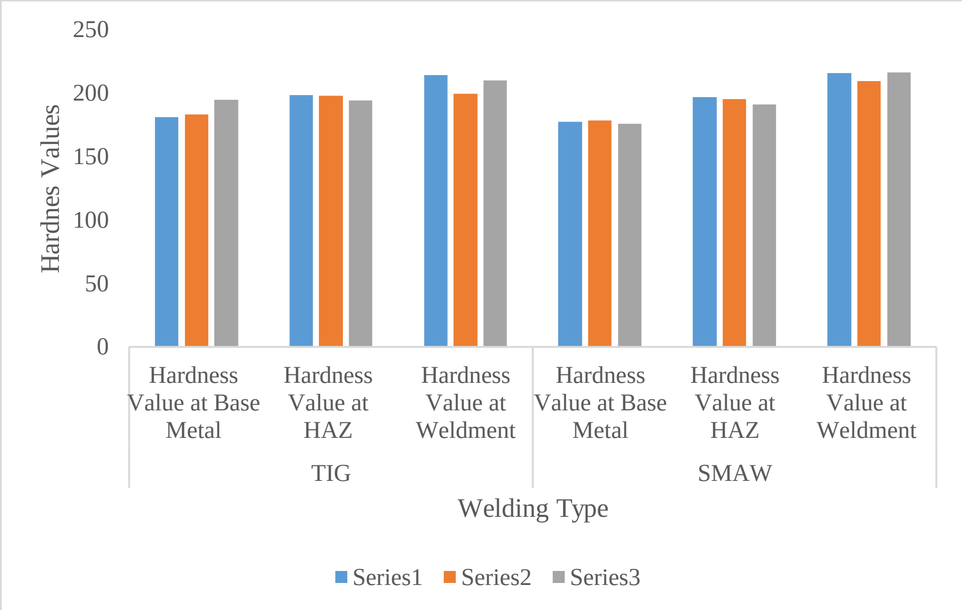

Figure 8: Hardness values for TIG and SMAW with varied welding Parameters

Table 5: Response Table for Signal to Noise Ratios for Hardness using TIG Welding Process

Level	Current	Voltage	Travel Speed
1	45.96	46.13	45.80
2	45.92	45.99	45.96
3	45.77	45.53	45.89
Delta	0.19	0.59	0.15
Rank	2	1	3

Note: Larger is better

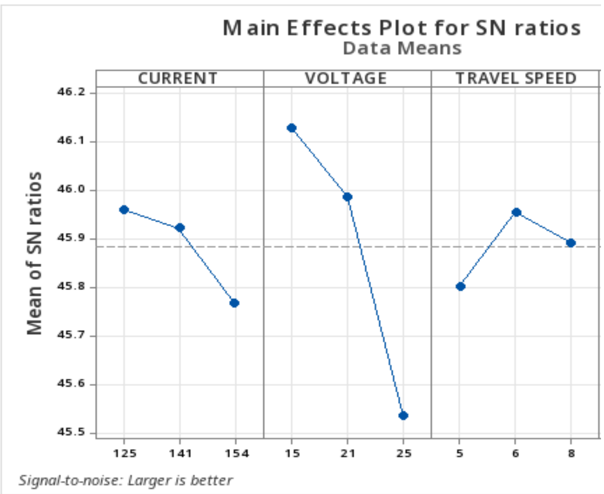

Figure 9: Plot for Welding parameters vs. S/N ratio for TIG

Table 6: Response Table for Signal to Noise Ratios for Hardness using SMAW Welding Process

Level	Current	Voltage	Travel Speed
1	45.87	45.54	45.66
2	45.84	45.80	45.85
3	45.62	46.00	45.82
Delta	0.25	0.46	0.19
Rank	2	1	3

Note: Larger is better

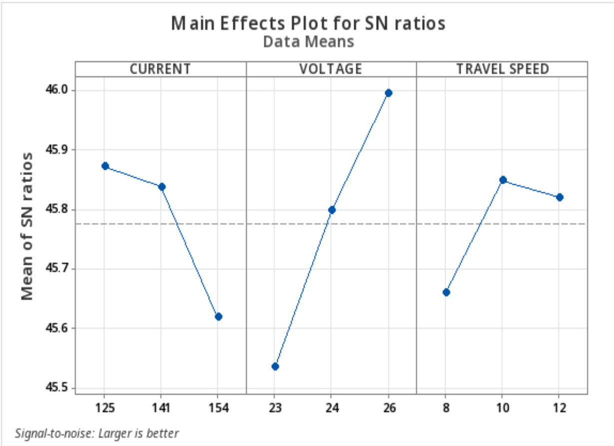

Figure 10: Plot for Welding parameters vs. S/N ratio for SMAW

Experiment Result and Analysis for Impact

From Figure 11, the experimental results show that TIG joints for samples 2, 3, 4, and 6 had better Charpy V-notched Impact toughness at room temperature than SMAW welded joints at the HAZ region, with sample 2 having 160 J/m^2 for TIG welded joint the HAZ. Whereas samples 1 and 5 indicated that SMAW joints at the HAZ had higher Impact strength as compared with TIG joints with sample 5 for SMAW having a value of 134 J/m^2. Taguchi's 'larger the better' for the TIG welding process, ranked Voltage first, current and travel speed 2nd, and 3rd, respectively, as significant to obtain the Impact strength optimum value as shown in Table 7 and Figure 12. Similarly, for SMAW, the optimum response for impact strength for welding parameters, Taguchi ranked travel speed as first, Current as second and voltage as third as shown in Table 8 and Figure 13.

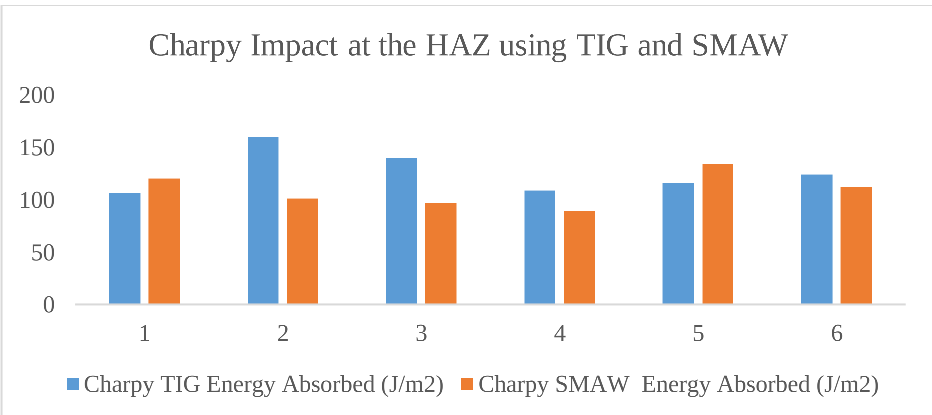

Figure 11: Impact values for TIG and SMAW with varied welding Parameters for Charpy test

Table 7: Response Table for Signal to Noise Ratios for Impact Strength using TIG Welding Process

Level	Current	Voltage	Travel Speed
1	45.96	46.13	45.80
2	45.92	45.99	45.96
3	45.77	45.53	45.89
Delta	0.19	0.59	0.15
Rank	2	1	3

Note: Larger is better

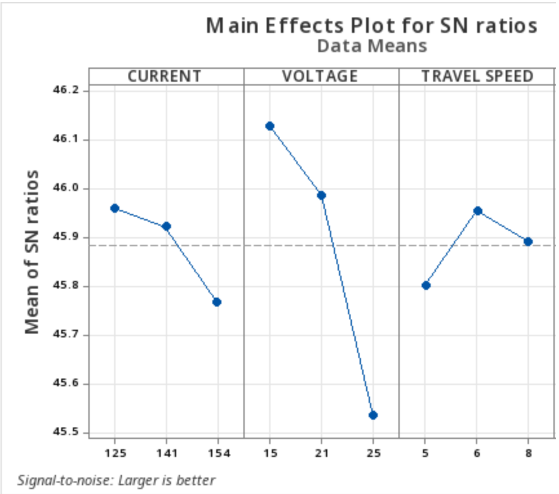

Figure 12: Impact Strength Plot for Welding parameters vs. S/N ratio for TIG

Table 8: Response Table for Signal to Noise Ratios for Impact Strength using SMAW Welding Process

Level	Current	Voltage	Travel Speed
1	45.94	46.33	45.82
2	45.88	45.89	45.98
3	45.76	45.63	45.86
Delta	0.18	0.57	0.16
Rank	2	1	3

Note: Larger is better

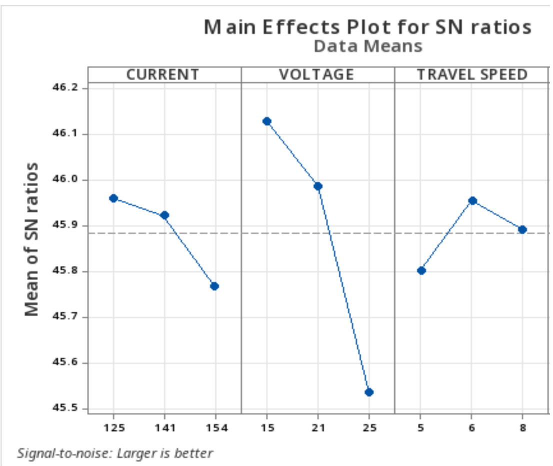

Figure 13: Impact Strength Plot for Welding parameters vs. S/N ratio for SMAW

CONCLUSION

This study examines the mechanical properties namely; Tensile strength, Hardness and Impact toughness of API 5L carbon steel pipe X65 at the Heat affected zone (HAZ) using Tungsten Inert Gas (TIG) and Shielded Metal Arc Welding (SMAW) processes considering the welding parameters such as Voltage, current and travel speed. The TIG welded joints at the HAZ gave the optimum value for tensile strength, hardness and Impact toughness as $5.879\text{x}10^5$ kN/m^2, BHN 198.6 and 160 J/m^2, respectively while the optimum for SMAW welded joints at the HAZ shown the for tensile strength, hardness and Impact toughness as $5.2235\text{x}10^5$ kN/m^2, BHN 196.7 and 134 J/m^2, respectively. Equally too, Taguchi analysis, ranked travel/welding speed, current and voltage as first, second and third respectively, to be considered as significant to achieve optimum value at the HAZ for UTS when using TIG and SMAW techniques whereas, for Hardness and Impact toughness, consideration could be given to Voltage first, closely followed by current and travel speed, respectively.

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