Journal of Multidisciplinary Engineering Science and Technology (JMEST)
ISSN: 2458-9403
Vol. 8 Issue 8, August - 2021

Experimental Investigation Of TIG Welding Parameters In Butt- Joint Configuration Of Mild Steel

Leonard Ngetich[1] Abel Mayaka[1] Charles Ondieki[1] Edward Odhong[1]
[1]Department of Mechanical and Mechatronics Engineering, Multimedia University of Kenya,
Nairobi, Kenya
[1]ngetichleonard08@gmail.com, abnmayaka@yahoo.com, charlesondieki@gmail.com, odhongedward@gmail.com

***Abstract*-Tungsten Inert Gas welding (TIG) process is most preferred welding technique in modern industries such as aerospace, oil and gas, nuclear, automotive industry as well as welding of industrial parts among other application. Gas Tungsten Arc Welding being a complex welding technique demands the service of skilled craftsman to execute the process. Understanding welding parameters matrices is very important step in simplifying tungsten inert gas welding while trying to reduce cost of production and at the same time improving on quality of weld pool.**

The experiment was carried out at workshop set-up whereby selected control parameters such as welding speed, welding current and gap-width were used in welding system to produce test-pieces for testing. The test-pieces were then subjected to quality testing of depth of penetration, beadwidth, heat affected zone and ultimate tensile strength. Investigating welding parameters such as welding speeds, current and gap width is the basis for control of welding attributes that will result in quality weld joint. The research attempted to determine experimentally optimal welding parameters that will result in a quality welded joint. From the experimental research, it was found out that TIG welding is strongly coupled multivariable process with optimal control parameters ; welding speeds of 120mm/min to 175mm/min applied alongside welding current range of 100Amps to 140Amps coupled with joint gap width of 0.15mm ±0.02mm for optimal welding parameters with excellent weld quality.

Keywords—Tungsten Inert Gas Welding; Weld pool; Control Parameter; Welding Attribute.

I. INTRODUCTION

TIG welding is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmosphere by an inert shielding gas (argon or helium), and a filler metal is normally used. The power is supplied from the power source, through a welding torch, delivered to a tungsten electrode which is fitted into the hand piece. An electric arc is then created between the tungsten electrode and the work piece using a constant-current welding power supply that produces energy and conducted across the arc through a column of highly ionized gas and metal vapors [1]. The tungsten electrode and the welding zone are protected from the surrounding air by inert gas. The electric arc can produce temperatures of up to 20,000^{0}C and this heat can be focused to melt and join two different parts of material. The weld pool can be used to join the base metal with or without filler material. Schematic diagrams of TIG welding system and TIG welding set-up are shown in Figure 1 and Figure 2 respectively.

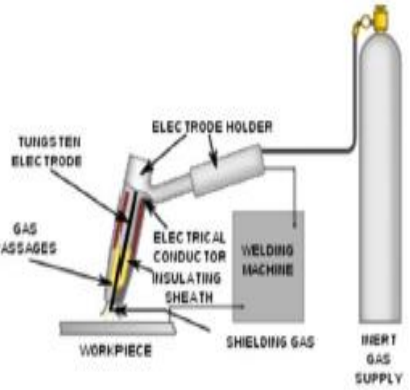


Fig. 1: Schematic Diagram of TIG Welding System **[2]**

TIG welding is the most commonly used welding technique to weld thin sections of stainless steel, non-ferrous metals such as aluminum, magnesium and copper alloys nowadays. It is becoming increasingly popular among industry experts due its extensive wide applications to weld variety of metallic materials while also welding complex geometries with precision. The quality of the weld joint obtained through this welding technique is good. The weld exhibit superior weld characteristics such as high tensile strength, fracture toughness, minimal welding defects and clean weld surface. However, it is significantly slower than most other welding techniques and comparatively more complex and difficult to master as it requires greater welder experience than metal inert gas welding (MIG) or stick welding. The TIG welding process, engineers more often are faced with the problem of selecting appropriate and optimum combinations of input control variables for the required weld pool quality [3]. Availing more information on TIG welding is therefore, necessary indeed. At optimal control variables, the weld pool exhibit desirable physical and geometric attributes. That information is of great value in welding components and sub-assemblies in industries in that it will help in machine set-up rather than relying on estimation of welding parameters.

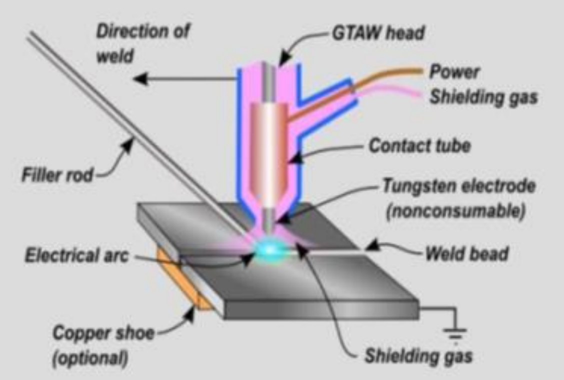


Fig. 2: TIG welding Set-up **[1]**.

The major quality issues often observed in TIG welding are due to welding defects such as undercutting, tungsten inclusions, porosity, heat affected zone cracks. These quality issues are associated with the control of welding speed, welding current and gap width. If repeatability of the welding process is achieved, quality is enhanced and quality control is simplified. Therefore, there is need to improve quality of welding process by minimizing these welding defects. Superior weld can withstand cyclic loads, thermal stresses and even vibrations.

TIG welding is known for being slower to execute, requires great deal of skills and patience and much harder to master as well. To respond to need of time and cost more information should be availed so that welding is performed at shortest time possible and with minimum defects.

Interaction of welding parameters is a complex relationship that needs to be investigated further. TIG welding is a highly non-linear, strongly coupled, multivariable process [4].The weld pool geometry and, hence, the quality of TIG welded joints are greatly dependent on the selection of input control variables such as welding speed (V), welding current (I), shielding gas flow rate (F) and gap distance (G).

The main objective of this research paper is to determine experimentally the optimal TIG welding parameters for quality butt-joint formation in mild steel.

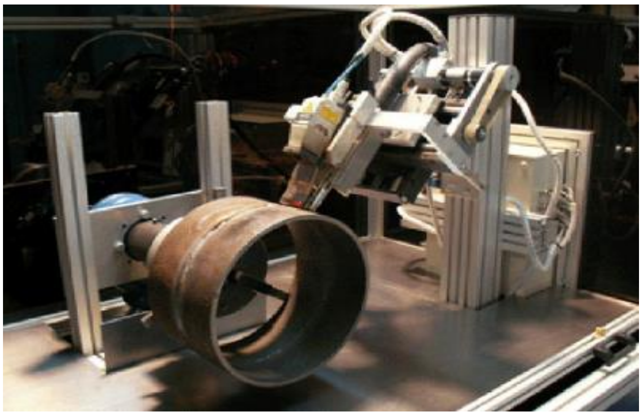


Fig. 3: Automated TIG welding cell-prototype **[5]**

With optimal control variables cell type in figure 3 can be easily automated with desired quality attributes being achieved.

II. MATERIALS AND METHODS

A. Experimental investigation of the effects of welding speed, welding current and gap width on the quality of welds in mild steel.

The experiment was carried out at workshop set-up at Kabete National Polytechnic whereby TIG test-pieces were produced as per design of experiment. Quality parameters of the test-pieces were then carried out at workshop set-up at Multimedia University of Kenya.

The welding setup consists mainly of the following parts:

i) TIG welding machine– This is the main part of TIG welding setup by which controlled amount of current and voltage is supplied during welding. A current range 10-180Amps and voltage up to 230 V, depending on the current setting will be used.
ii) Gas cylinder- For TIG welding Helium gas is supplied to the welding torch with a particular flow rate so that an inert atmosphere formed and stable arc created for welding. Gas flow is control by regulator and valve.
iii) Work holding table- a surface plate (made of grey cast iron) is used for holding the work piece so that welding gap between the tungsten electrode and work piece is maintained. Proper clamping has been used to hold the work piece (figure 10).
iv) The torch was maintained at an angle of approximately 90° to the work piece.

B. TIG welding equipment specification

The welding equipment is TIG welding machine with welding current of (10-200 Amps) and rated input power of 4.6 KVA. This welding machine is suitable while considering current range which is within the experiment test range of this research. The machine has adjustable knob which allows the operator to select the current requirement. The machine is therefore ideal for carrying out the experiment at Kabete National Polytechnic mechanical workshop.

C. Work piece preparation

Commercial mild steel bar of thickness 3mm was selected as work piece material for this experiment. Mild steel bar was cut with dimension of 50 mm × 12.5 mm according to E8M-13 standard with the help of band-saw, setsquare and a scriber. Grinding and polishing was done at the edge to smoothen the surface to be joined. After that the surfaces were etched with dilute sulphuric acid to remove any kind of external material or dirt and oxides from the surface. The specimens were then thoroughly cleaned with tap water to remove acid residue.

D. Work setting and clamping

This step involves the process of setting the surface plate on setting table. With the help of a spirit level, the surface plate is set as shown in plate 1. This setting ensures that the relative motion between the surface plate and welding torch is precisely parallel. That therefore enhances constant arc length during TIG welding.

Plate 1: Laboratory TIG Set-up

The welding jig was designed as shown in figure 4. The purpose of welding jig is to locate the workpieces on a setting table accurately while assisting in work holding at the same time. This assembly enhances accurate setting of welding gap width as stipulated in welding procedure. The jig has a groove dimensioned in such a way that the specimen is just located in the groove; the bolt and nut assembly assists in accurate adjustment of the gap width with the help of filler gauges as in plate 2.

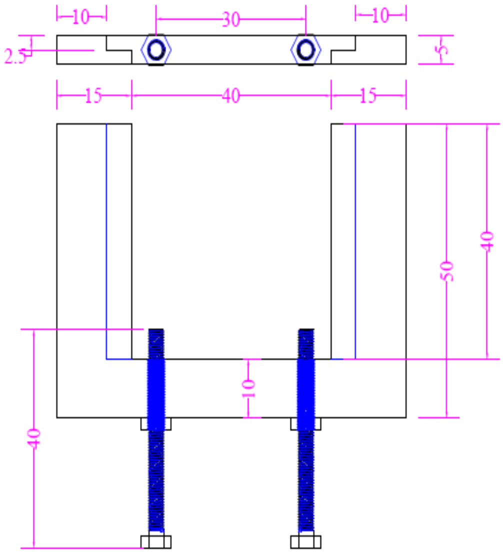


Fig.4: welding jig views (source)

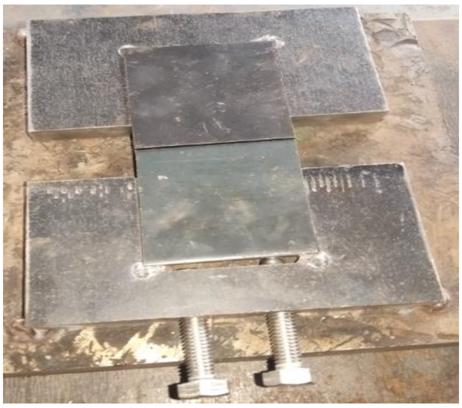


Plate 2: workpiece holding

The specimens were then fixed in the working table with flexible clamp side by side with the help of welding jig.

Plate 3: Workpiece clamping ready for TIG welding

With the help of filler gauges, the clearance of <0.1mm, 0.1mm and 0.2mm were measured as in plate 3.

Welding was then done with a single pass so that a butt joint can be formed as in figure 5. The servomechanism of lathe machine was adapted to generate variable speeds as specified in design of experiment as shown in plate 4. Once the intended welding control parameters have been selected, the welding machine is switched on, then the mechanism of lathe machines takes on automatically generating linear movement of welding torch accurately. The weld formed is smooth and homogeneous exhibiting the desired welding speed. Test-pieces was produced with this procedure according to design of experiment. TIG welding with Direct current (DC) was used in experiments as recommended.

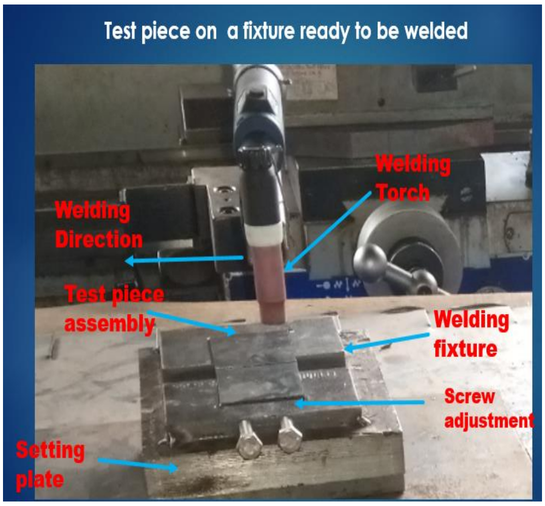


Plate 4: Specimen clamping on setting table

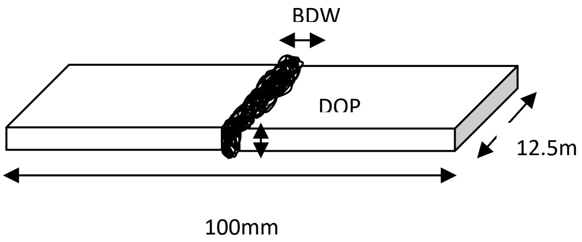


Fig. 5: Joining process (butt joint) (source)

E. Welding procedure

The selected GTAW parameters were:

i. GTAW current
ii. Welding speed
iii. Gap width

These parameters were combined and used to evaluate welding attributes (bead width, DOP, HAZ, tensile strength). Thereafter, relationship was established between welding parameters and physical and geometric attributes of weld joint. Experimental set-up is shown in figure 6.

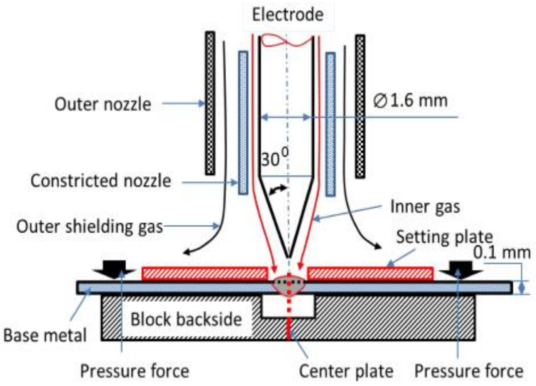


Fig. 6: Schematic illustration of setting the experiment **[6]**.

F. Welding of specimens

Each step involved the following tasks in order:

i) Varying welding speed at different levels of gap width while keeping current constant at given value. The speed envelope was increased gradually at varying levels of gap widths as shown in table 1.
ii) Varying welding current while keeping welding speed constant at changing levels of gap width as shown in table 2.
iii) Varying welding current against welding speed concurrently while maintaining gap width at specific value as shown in table 3.

The schematic illustration of joint formation is as shown in figure 5.The welded samples for welding current of 100Amps and welding speed of 210mm/s and 150mm/s are shown in plate 5. The specimen with welding speed of 150mm/min exhibit good weld characteristics as compared to the one for welding speed of 210mm/min.

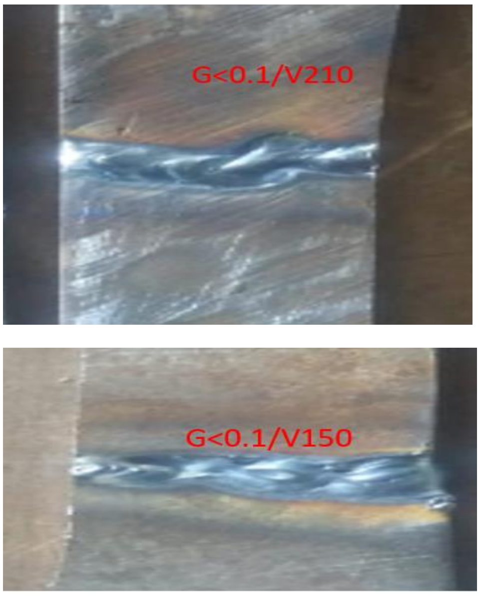


Plate 5: Welded sample for current of 100Amps, welding gap of 0.1mm and welding speed of 210mm/sec and 150mm/sec respectively.

The welded specimens ready for testing is as shown in plate 6. Five welded specimens were produced per experiment.

Plate 6: Sample welded specimens ready for testing

G. Testing of specimens

The procedure involved taking measurements of heat affected zone and bead width using Vernier caliper while recording them in data collection sheet. Tensile test was then done on each specimen using universal tensile testing machine according to EM8 standard. Depth of penetration was then measured from the specimens from tensile testing using micrometer screw gauge. The average parameter was calculated for the five samples of each experiment for analysis.

III. RESULTS AND DISCUSSIONS

A. Experimental Data

The experimental data for different control parameters as set out in experimental design is shown in table1, table 2 and table 3.

Table 1: Experimental data for a welding current of 100 Amps. Quality tests results (factorials-welding speed/gap width-Average parameter)

GAP(mm) G	Welding speed (V) mm/min welding current=100Amps					
	90		150		210	
	Quality parameter (DOP,BDW,HAZ,UTS)					
<0.1	TEST PIECE	AVR PRMT	TEST PIECE	AVR PRMT	TEST PIECE	AVR PRMT
	DOP(mm)	2.58	DOP	2.16	DOP	0.96
	BDW(mm)	6.16	BDW	5.84	BDW	4.32
	HAZ(mm)	7.58	HAZ	6.64	HAZ	5.68
	UTS(N/mm^2)	181.02	UTS	171.58	UTS	143.44
0.1	TEST PIECE	AVR PRMT	TEST PIECE	AVR PRMT	TEST PIECE	AVR PRMT
	DOP(mm)	2.9	DOP	2.62	DOP	1.76
	BDW(mm)	6.42	BDW	5.68	BDW	4.2
	HAZ(mm)	6.0	HAZ	5.78	HAZ	3.58
	UTS(N/mm^2)	220.52	UTS	210.1	UTS	191.09
0.2	TEST PIECE	AVR PRMT	TEST PIECE	AVR PRMT	TEST PIECE	AVR PRMT
	DOP(mm)	2.38	DOP	1.76	DOP	1.12
	BDW(mm)	6.46	BDW	5.72	BDW	4.26
	HAZ(mm)	5.78	HAZ	4.4	HAZ	3.62
	UTS(N/mm^2)	215.56	UTS	207.31	UTS	182.26

Table 2: Experimental data for a welding speed of 210mm/min. Quality tests results (factorials-welding current/gap width-Average parameter).

GAP(mm) G	Welding current (I) Amps			welding speed=210mm/min		
	80		100		130	
	Quality parameter (DOP,BDW,HAZ,UTS)					
<0.1	TEST PIECE	AVR PRMT	TEST PIECE	AVR PRMT	TEST PIECE	AVR PRMT
	DOP(mm)	1.66	DOP	2.5	DOP	2.94
	BDW(mm)	5.86	BDW	5.96	BDW	7.78
	HAZ(mm)	3.62	HAZ	4.88	HAZ	6.08
	UTS(N/mm^2)	169.92	UTS	182.41	UTS	221.63
0.1	TEST PIECE	AVR PRMT	TEST PIECE	AVR PRMT	TEST PIECE	AVR PRMT
	DOP(mm)	2.02	DOP	2.82	DOP	2.98
	BDW(mm)	5.60	BDW	6.42	BDW	7.0
	HAZ(mm)	4.5	HAZ	5.07	HAZ	6.38
	UTS(N/mm^2)	173.27	UTS	206.72	UTS	234.96
0.2	TEST PIECE	AVR PRMT	TEST PIECE	AVR PRMT	TEST PIECE	AVR PRMT
	DOP(mm)	1.44	DOP	2.42	DOP	2.8
	BDW(mm)	6.02	BDW	6.24	BDW	8.042
	HAZ(mm)	4.48	HAZ	4.8	HAZ	7.2
	UTS(N/mm^2)	114.36	UTS	153.0	UTS	218.1

Table 3: Experimental data for a gap width of 0.15mm. Quality tests results (factorials-welding speed/welding current-Average parameter)

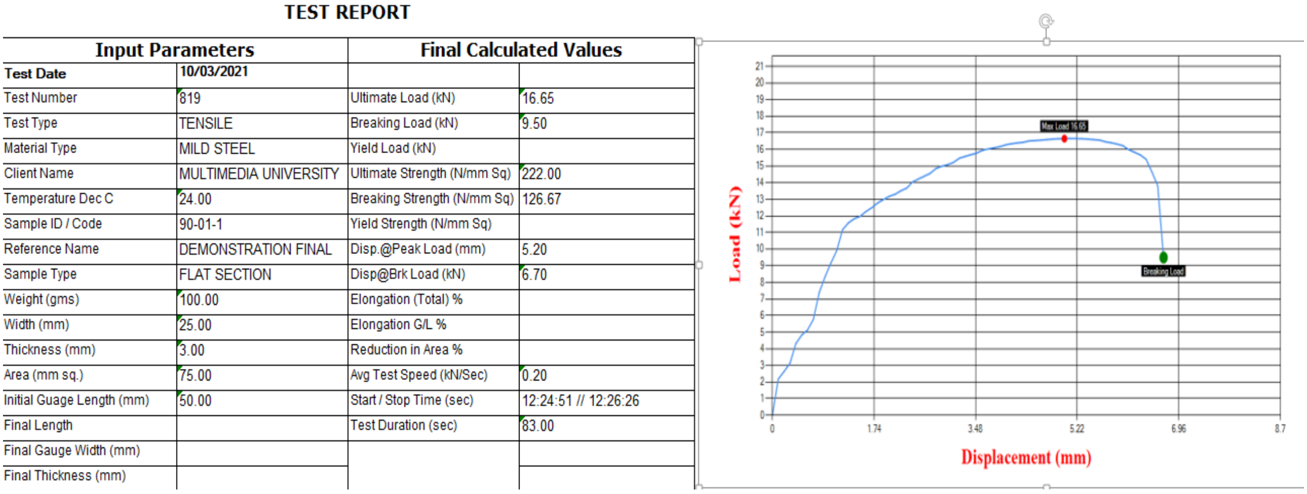
WELDING SPEED (mm/min)	Welding current (I)Amps				Gap width =0.15mm	
	80		100		130	
	Quality parameter (DOP,BDW,HAZ,UTS)					
90	TEST PIECE	AVR PRMT	TEST PIECE	AVR PRMT	TEST PIECE	AVR PRMT
	DOP(mm)	1.0	DOP	1.32	DOP	2.28
	BDW(mm)	5.58	BDW	6.6	BDW	6.95
	HAZ(mm)	6.08	HAZ	6.36	HAZ	6.86
	UTS(N/mm^2)	137.86	UTS	188.62	UTS	210.5
150	TEST PIECE	AVR PRMT	TEST PIECE	AVR PRMT	TEST PIECE	AVR PRMT
	DOP(mm)	1.6	DOP	2.56	DOP	2.98
	BDW(mm)	6.2	BDW	6.48	BDW	6.94
	HAZ(mm)	4.08	HAZ	5.16	HAZ	5.58
	UTS(N/mm^2)	227.44	UTS	251.04	UTS	255.10
210	TEST PIECE	AVR PRMT	TEST PIECE	AVR PRMT	TEST PIECE	AVR PRMT
	DOP(mm)	1.3	DOP	2.92	DOP	3.0
	BDW(mm)	4.84	BDW	6.16	BDW	7.42
	HAZ(mm)	2.94	HAZ	5.36	HAZ	5.92
	UTS(N/mm^2)	116.2	UTS	229.7	UTS	264.14

From the experimental data analysis the following observations were made:

B. Trends in heat affected zones (HAZ)

The research attempted to obtain optimal combination of welding speed, welding current and gap width that minimizes HAZ at weld joint. The highest HAZ is 7.58mm while doing welding speed of 90mm/min and welding current of 100Amps while the lowest HAZ is 2.94mm while doing a welding speed of 210mm/min at welding current of 80Amps. However it is worth considering other quality parameters such as ultimate tensile strength and depth of penetration of the joint. When these other parameters are considered, a welding speed of 210mm/min with welding current of 130Amps and a gap width of 0.15mm is suitable for minimal HAZ without compromising on other quality parameters.

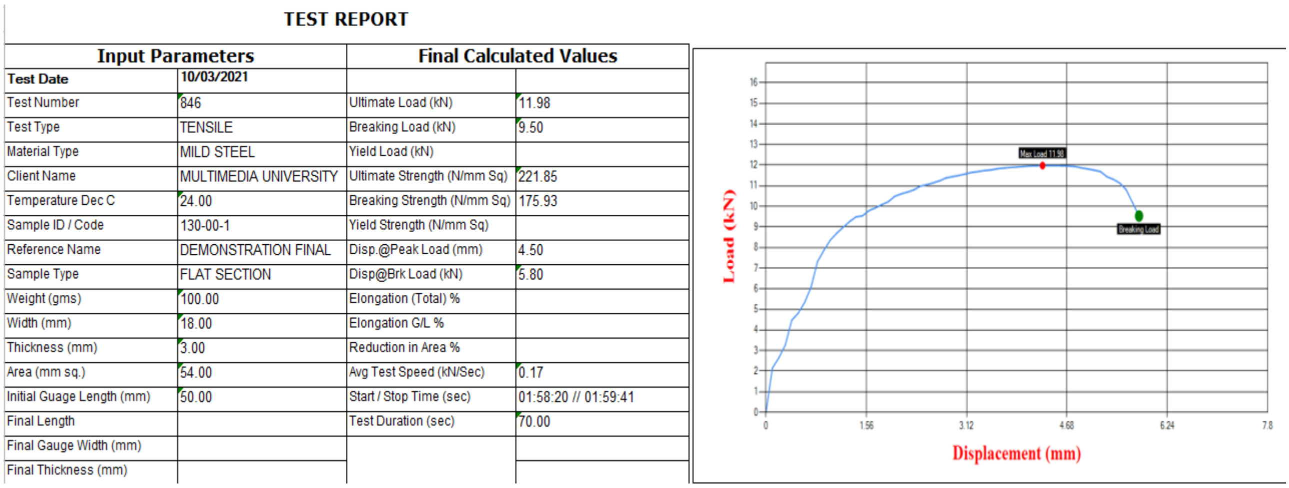
C. Trends in tensile loading



TEST REPORT

Input Parameters		Final Calculated Values	
Test Date	10/03/2021		
Test Number	819	Ultimate Load (kN)	16.65
Test Type	TENSILE	Breaking Load (kN)	9.50
Material Type	MILD STEEL	Yield Load (kN)	
Client Name	MULTIMEDIA UNIVERSITY	Ultimate Strength (N/mm Sq)	222.00
Temperature Dec C	24.00	Breaking Strength (N/mm Sq)	126.67
Sample ID / Code	90-01-1	Yield Strength (N/mm Sq)	
Reference Name	DEMONSTRATION FINAL	Disp.@Peak Load (mm)	5.20
Sample Type	FLAT SECTION	Disp@Brk Load (kN)	6.70
Weight (gms)	100.00	Elongation (Total) %	
Width (mm)	25.00	Elongation G/L %	
Thickness (mm)	3.00	Reduction in Area %	
Area (mm sq.)	75.00	Avg Test Speed (kN/Sec)	0.20
Initial Guage Length (mm)	50.00	Start / Stop Time (sec)	12:24:51 // 12:26:26
Final Length		Test Duration (sec)	83.00
Final Gauge Width (mm)			
Final Thickness (mm)			

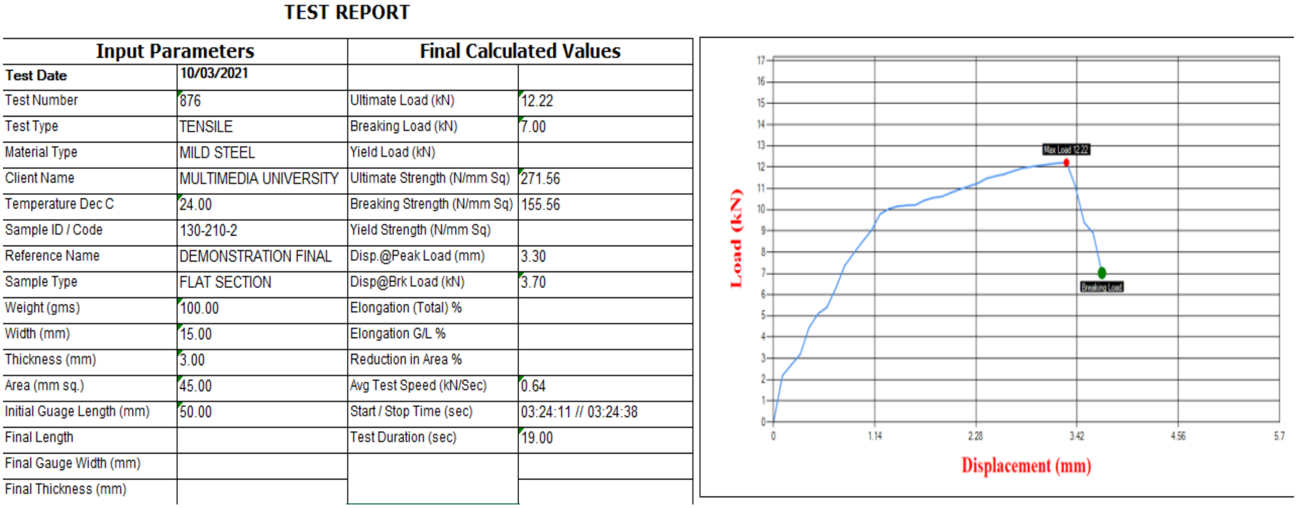
Fig. 7: Tensile test report for welding speed of 90mm/min, current 100Amps, gap width 0.1mm



TEST REPORT

Input Parameters		Final Calculated Values	
Test Date	10/03/2021		
Test Number	846	Ultimate Load (kN)	11.98
Test Type	TENSILE	Breaking Load (kN)	9.50
Material Type	MILD STEEL	Yield Load (kN)	
Client Name	MULTIMEDIA UNIVERSITY	Ultimate Strength (N/mm Sq)	221.85
Temperature Dec C	24.00	Breaking Strength (N/mm Sq)	175.93
Sample ID / Code	130-00-1	Yield Strength (N/mm Sq)	
Reference Name	DEMONSTRATION FINAL	Disp.@Peak Load (mm)	4.50
Sample Type	FLAT SECTION	Disp@Brk Load (kN)	5.80
Weight (gms)	100.00	Elongation (Total) %	
Width (mm)	18.00	Elongation G/L %	
Thickness (mm)	3.00	Reduction in Area %	
Area (mm sq.)	54.00	Avg Test Speed (kN/Sec)	0.17
Initial Guage Length (mm)	50.00	Start / Stop Time (sec)	01:58:20 // 01:59:41
Final Length		Test Duration (sec)	70.00
Final Gauge Width (mm)			
Final Thickness (mm)			

Fig. 8: Tensile test report for welding current of 130 Amps, welding speed 210mm/min, gap width <0.1mm



TEST REPORT

Input Parameters		Final Calculated Values	
Test Date	10/03/2021		
Test Number	876	Ultimate Load (kN)	12.22
Test Type	TENSILE	Breaking Load (kN)	7.00
Material Type	MILD STEEL	Yield Load (kN)	
Client Name	MULTIMEDIA UNIVERSITY	Ultimate Strength (N/mm Sq)	271.56
Temperature Dec C	24.00	Breaking Strength (N/mm Sq)	155.56
Sample ID / Code	130-210-2	Yield Strength (N/mm Sq)	
Reference Name	DEMONSTRATION FINAL	Disp.@Peak Load (mm)	3.30
Sample Type	FLAT SECTION	Disp@Brk Load (kN)	3.70
Weight (gms)	100.00	Elongation (Total) %	
Width (mm)	15.00	Elongation G/L %	
Thickness (mm)	3.00	Reduction in Area %	
Area (mm sq.)	45.00	Avg Test Speed (kN/Sec)	0.64
Initial Guage Length (mm)	50.00	Start / Stop Time (sec)	03:24:11 // 03:24:38
Final Length		Test Duration (sec)	19.00
Final Gauge Width (mm)			
Final Thickness (mm)			

Fig. 9: Tensile test report for welding current of 130 Amps, welding speed 210mm/min, gap width 0.15mm

The tensile test report in figure 7, figure 8 and figure 9 are sample reports indicating ultimate tensile strength of TIG weld joint of welded specimens as shown in table 1, table 2 and table 3.

UTS (ultimate tensile strength) is a function of heat energy input. Heat energy input on the other hand is a function of welding speed, welding current and machine voltage as shown in equation 1.

$$E(J/mm) = \frac{VI}{S} \qquad (1)$$

Where by V is machine voltage, I welding current and S is welding speed. E is heat energy input. The relationship between heat energy and welding speed is direct proportionality while welding speed is inverse proportionality. This relationship therefore explains the UTS data trends in table1 and table 3 whereby welding speed is a variable. Welding voltage of TIG welding machine is in the range of $19 \leq V \leq 24$. It also explains the trends in table 2 whereby current is the variable.

Suppose the welding voltage is 25voilts, current is 100Amps and welding speed is 90mm/min (1.5mm/sec) then:

$$E = \frac{25 \times 100}{1.5}$$

$$= 1.666KJ/mm$$

Increasing welding speed to 210mm/min (3.5mm/sec), then:

$$E = \frac{25 \times 100}{3.5}$$

$$= 0.714KJ/mm$$

Therefore higher welding speeds results in lower heat energy inputs hence less depth of penetration and poor bonding strength resulting in lower UTS. Again increasing welding current result in high heat energy inputs hence higher UTS. The trend of UTS of weldment with varying heat energy input can be attributed to the weld penetration depth and bonding strength at the weld joints. The initial increase in UTS is due to increase in bonding strength and penetration as the heat energy per unit length is increased. However, there is sudden decrease in UTS with increase in heat energy input. At this juncture, the variation in the microstructure of the fusion zone with heat energy input played a role. That is further increase in heat energy input has no significant effect on weld joint bonding strength and weld penetration depth.

D. Trends in Beadwidth

The following major observations were made regarding BDW. BDW increase with welding current while it decreases with increase in welding speed. The explanation concerning this phenomenon is attributed to heat energy input which is explained by equation 1. The more heat input, the more DOP, hence more BDW. Positive relationship has been established between beadwidth and tensile strength of the weld joint. This is attributed to improved bonding strength as BDW increases. There is negligible effect in BDW as gap width is increased, that implies gap width is not a factor when determining BDW. Finally, bead width is a good visual indicator for weld depth of penetration, bonding strength and physical attributes of weld-bead with respect to welding defects.

E. Trends in depth of penetration

The following major observations were made regarding DOP. DOP increase with welding current while it decreases with increase in welding speed. The explanation concerning this phenomenon is attributed to heat energy input which is explained by equation 1. The more heat input, the more DOP, hence more metal fusion at weld joint. Positive relationship has been established between depth of penetration and tensile strength of the weld joint. This observation is attributed to improved bonding strength as DOP increases. There exist a critical value of welding current and gap width beyond which the depth of penetration starts to decline. A current of 120Amps and a gap width of 1.5mm are the optimal parameters for excellent depth of penetration.

IV. CONCLUSION AND RECOMMENDATION

A. Conclusion

In this present work, effect of welding parameters on quality of the weld joint of TIG welding in mild steel was successfully investigated. The welding parameters that were investigated are welding speed, welding current and gap width of joint geometry. The quality was assessed based on quality parameters such as bead width, depth of penetration, heat affected zone and ultimate tensile strength. Based on the results obtained, the following conclusion can be drawn:

i. Numerical modeling of effect of welding parameters on physical and geometric attributes of weld joint is feasible. The numerical models fairly predicts the expected optimal values of welding control parameters that exhibit good welding attributes in terms of quality.

ii. Welding current is an important factor in heat energy input equation that dictates the quality parameters of weld joint. Low welding currents minimizes heat affected zones but it compromise on depth of penetration of weld and undermines tensile strength of the joint. Increasing the welding current results in average or complete depth of penetration with positive effect on tensile strength of the joint. Excessive welding currents generates adverse welding defects such as metal spatter, porosity and excessive weld penetration. A current of 100Amps-140Amps is ideal for TIG weld generation with good or excellent quality. Currents in excess of 140Amps does not guarantee good quality just like the currents below 100Amps.

iii. Welding speed is also an important factor in heat energy input equation that dictates the quality parameters of weld joint. Low welding speeds maximizes depth of penetration with significant improvement in ultimate tensile strength of the joint. Low welding speeds facilitate sufficient welding time for weld to percolate through the joint just enough for fusion to take place at the same time allows enough heat energy input to dissipate for the purpose of melting the base metal. However, extremely low speeds result in pronounced HAZ which undermines the region around the weld joint. High welding speeds on the other hand minimizes HAZ but undermine the weld quality by limiting the depth of penetration hence insufficient fusion of weld resulting in low tensile strength of the joint. Welding speeds of 120mm/min-175mm/min are ideal for enhancing excellent depth of penetration and optimal ultimate tensile strength while minimizing heat affected zones.

iv. Joint preparation is a very important task for any professional and average TIG welder while designing a weld joint. Therefore, gap width plays a major role in dictating quality attributes of the joint. From the research it was observed that small gap width of less than 0.1mm undermines depth of penetration and ultimate tensile strength. The explanation for this was that the small gap interrupts the lamina flow of molten metal for metal fusion to take place effectively. The weld pool is therefore very thinly distributed in the joint hence inadequate metal fusion. Conversely, increasing a gap width to 0.2mm result in the decline in in depth of penetration and consequently reduced tensile strength of the joint. When gap width is increased beyond certain critical value, undesirable welding defects such as under-fill were noticeable. Porosity was also evident but this situation can be mitigated by using filler material. Gap width had no significant effect on HAZ. The gap width of 0.15mm was observed to be ideal geometrically for enhancing good quality attributes of the joint.

B. Recommendation

TIG welding is strongly coupled multivariable process and for this reason I am recommending welding speeds of 120mm/min-175mm/min applied alongside welding current range of 100Amps-140Amps coupled with joint gap width of 0.15mm ±0.02mm for optimal welding parameters with excellent weld quality.

C. Recommendation For Further Work

i. Since the TIG is the welding technology for current and future large scale industrial applications, there is need to refine this technique with a view of making the TIG welding process adaptable and reliable. For this reason, I am recommending that the welding parameters be subjected to strong computation algorithms such as metaheuristics in order to fully characterize and visualize interaction of welding parameters with physical and geometric attributes. This major step will enhance application of artificial intelligence (AI) in choosing welding parameters for flexible manufacturing system. With inception of artificial intelligence, virtual reality (VR) will be realized with the goal of doing virtual modeling of TIG welding process from which design changes will be effected before exporting the data for component fabrication.

ii. Further specific research should be undertaken on individual cutting edge metallic materials such as different grades of steel and emerging grades of titanium and aerospace grade aluminum among others in order to refine control parameters to suit optimal quality welding attributes of these specific materials.

ACKNOWLEDGMENT

I wish to sincerely thank Kabete National Polytechnic for granting me their promises for this research. Special thanks also goes to Kabete technical staff for granting me unconditional support.

REFERENCES

[1] P. N. Patel, "A Review of Parametric Optimization of Tig Welding," *International Journal of Computational Engineering Research,* no. 04, pp. pp 27-31, 2014.

[2] N. Ramesh, "Parametric Optimization of TIG Welding Process in Butt Joining of Mild Steel and Stainless Steel," *International Journal of Current Engineering and Technology,* no. 6, 25 October 2016.

[3] B. Kokangul, "Mathematical Modeling for Prediction and Optimization of TIG Welding Pool Geometry," 2008.

[4] R. K. L. L. Y.M. Zhang, "Characterization and real-time measurement of geometrical appearance of the weld pool," *Int. J.Mach. Tools Manuf,* vol. 36, no. 7, pp. 799-816, 1996.

[5] S. Barik, "Advancement in welding technology and Materials: Improving Productivity," ROURKELA, 2013.

[6] P. Mohan, "Study The Effects of Welding Parameter on TIG Welding of Aluminium Plate," 2014.

[7] K. Esme, "Mathematical Modeling For Prediction," *Metalurgija,* 2009.