Research & Reviews: Journal of Material Sciences e-ISSN: 2321-6212

Study the Effect of Welding Parameters on Distortion of AA6061-T6 Butt Joints Made by MIG Welding (Robotic GMAW)

Milad Bahrami*, Michel Guillot

Department of Mechanical Engineering, Laval University, Quebec, Canada

Research Article

Received: 27-Jul-2022, Manuscript No. JOMS-22-70581; **Editor assigned:** 29-Jul-2022, PreQC No. JOMS-22-70581 (PQ); **Reviewed:** 12-Aug-2022, QC No. JOMS-22-70581; **Revised:** 19-Aug-2022, Manuscript No. JOMS-22-70581 (R); **Published:** 29-Aug-2022, DOI: 10.4172/2321-6212.10.8.002.

***For Correspondence:**

Milad Bahrami, Department of Mechanical Engineering, Laval University, Quebec, Canada

E-mail: milad.bahrami.1@ulaval.ca

Keywords: Gas metal arc welding; Butt joint; Welding parameters; Distortion; Mechanical properties; Taguchi design of experiments; Artificial neural network modeling

ABSTRACT

The main goal of this study is to look into how Gas Metal Arc Welding affects the shape of AA6061-T6 aluminum when it is welded (GMAW). Variations in Voltage (V), Wire Feed Speed (WFS), Gun Angle (GA), Travel Speed (TS), Distance from the nozzle to the Spot to be Welded (DISW), Root Gap (RG), and Root Face (RF) are used as welding parameters. This gives the Simufact software the information it needs to simulate the arc welding process at a room temperature of 20°C. The simulation results from Finite Element Analysis (FEA) software show that the amount of distortion is large, so simulating the welding process helps people understand how welding works and compares to experimental results. The results also show that there is a link between the parameters of welding and the amount of distortion. The type of welding wire is 5356. It has a 1.2 mm diameter and is made of 100% Argon. It has a 25 cfh flow rate. CMM was used to measure samples of welding to find out how much and what kind of distortion there was. The experiments are planned with the help of the Taguchi method, and Artificial Neural Network (ANN) modeling is used to predict how the joints will bend. The results show that the main things that cause or change distortions are wire feed speed, voltage, and travel speed. When the wire feed speed and voltage are both increased at the same time, distortion gets worse. This shows that these parameters and variables in welding have a big effect on distortion.

INTRODUCTION

Aluminum is a material that is used a lot all over the world. Whether it's a sheet, plate, extruded bar, or profile, 6061 is the best choice for a wide range of uses, including boats and ships, building and bridge construction, and structural applications [1].

Gas Metal Arc Welding (GMAW) is a fast, cheap method that is also known as Metal Inert Gas (MIG) welding [2]. In Gas Metal Arc Welding (GMAW), a solid wire is used as both the electrode and the filler metal. An inert shielding gas protects the arc and the weld pool, as shown in Figure 1a and Figure 1b [3]. Most of the time, there are two ways to get welding deformation, which are the experimental and numerical simulation methods. FEA is used to simulate the welding process because it has a lot of benefits, including the ability to include non-linear aspects that change with temperature when modelling highly multi-physics problems in the welding process [4-6]. On the other hand, numerical studies on the thermo-mechanical behavior of welded structures and the analysis of finite elements, along with experimental studies, are a good way to figure out how the distortion will be spread out [7-9].

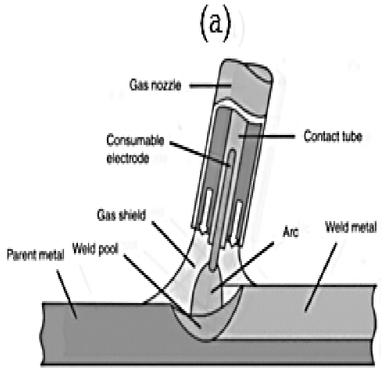
Even though there have been a lot of studies on how welding parameters and process parameters [10-12] affect the quality of butt joints made with the MIG technique, not much has been done on output distortion and mechanical properties when robotic welding is used. Some studies have shown how welding parameters like voltage affect distortion [13]. Another search looked at the effect of only one parameter, like amperage, on mechanical properties and distortion [14,15].

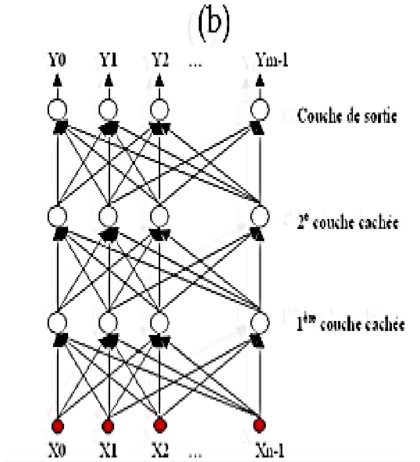
Many studies have investigated the effects of the welding parameters on distortion and mechanical properties on friction stir welding on aluminum [16-18]. Several searches have yielded information on the effects of welding parameters on distortion, mechanical properties, penetration, and other important laser welding outputs for aluminum alloy [19,20].

In the past, a lot of research has been done to find out how the welding parameters affect the GMAW welding process for aluminum alloy. In their study, Emine et al. [21] looked at the properties of AA5754 and AA6013 aluminum alloys that were joined together using automatic GMAW. Huang et al. [22] found that the direction of welding affects how the microstructure of 5083 aluminum alloy is characterized in fiber laser-GMAW hybrid welding. Mizuno et al. [23] looked at the relationship between restraint intensity and weld cracking in aluminum alloy welding. They also found that the right cross-sectional shape of the weld bead is very important and that the welding parameters should be carefully chosen to avoid cracks.

Artificial Neural Networks (ANNs) are computer programs that are based on the way the human brain works to simulate how it processes information [24]. In recent years, computer-aided Artificial Neural Network (ANN) modeling has become more important in the field of joining materials. An Artificial Neural Network (ANN) is a good way to model manufacturing processes like cutting, shaping, and bending metal. The linear and curvilinear multiple regression models are less accurate than the neural network model [25]. Figure 2 is a diagram of Artificial Neural Networks (Y_0 to Y_{m-1}).

Figure 1: (a) Schematic illustration of Gas Metal Arc Welding (GMAW) process. (b) Schematic of the Artificial Neural Networks.





There have been a lot of studies done on how to get the best results when using GMAW to weld steel and aluminum. However, there haven't been as many studies done on how the welding parameters affect the mechanical properties and distortion. Friction stir welding, flux core arc welding, and submerged arc welding have all been looked at in depth. In this study, the simulations show that the parameters of the heat source don't have a big effect on residual stress, but they do have an effect on welding deformation. In Chaitanya et al. [26], it was found that friction stir welding the high heat input joints broke from a Heat Affected Zone (HAZ) next to a Thermo-Mechanically Affected Zone (TMAZ) on the advancing side, while the low heat input joints broke from a weld nugget along a zigzag line on the advancing side. Mechanical properties improved when welding speed was reduced, rotation speed was increased, or heat input per unit length of weld was increased. During the welding process, the weld metal and the base metal next to it expand and contract as they heat and cool. This causes distortion in the weld. Distortions are thought to be affected by different geometric and welding process parameters. Angle distortion is one of the most common types of distortion that can be seen in butt-welded plates. If the sample is held still while it is being heated, it can't spread out laterally. But since the sample must get bigger as it heats up, it grows in the vertical direction and gets thicker. When the sample that was bent gets back to room temperature, it will still tend to shrink in all directions at the same rate. Now, the piece is shorter but thicker. It has changed in a way that can't be fixed. According to industry experience, there are a few, but not very important, ways to reduce distortion. These include not over welding; using intermittent welding, making as few weld passes as possible, balancing welds around the neutral axis, using backstep welding, predicting shrinkage forces; planning the welding sequence; and reducing welding time. In a study, the effect of welding parameters and process parameters on the quality of AA6061-T6 butt joints made with MIG welding was looked at. The experiments are planned with the Taguchi method in mind. Then, using Simufact software, FEA was done under the same conditions as the experiments, and the results were compared. Then, ANN modeling is used to predict how the voltage, wire feed speed, gun angle, travel speed, distance of the nozzle to weld, root gap, and root face parameters will affect the distortion during the welding process.

MATERIALS AND METHODS

In this search for material, the MIG process is employed to make the single butt joints of AA6061-T6 of 6.35 mm thickness with a 60-degree angle. Table 1a presents the chemical composition and mechanical properties of the base metal according to the specifications provided by the extruder. The wire metal used for the process is 5356 with a 1.2 mm diameter. Table 1b shows the material properties of this wire. Also, 100% Argon is used for gas protection with a flow of 25 cfh.

In this study, 6.35 x 76.2 x 203 mm 6061-T6 flat bars are machined to prepare root passes of 1.5 mm, 2 mm, and 2.5 mm. Root gaps were used from 0 mm to 0.2 mm, set using calibrated shims. Figure 2a shows the current sample for this study, and Figure 2b shows the preparation for the single V butt weld joint. Before starting the process, the samples have been cleaned with acetone to make sure there is no dirt and dust on the joint preparation before the weld. The welds are made by a FANUC R2000 Robot with a Miller Auto 750 welding process (Figures 3a, 3b, and 3c).

Table 1: (a) Material properties of Al 6061-T6 (base metal) (b) Material properties of Al5356 (consumable).

a.

Physical Properties	Metric	Component	Wt%
Hardness, Vickers	107	Al	95.8-98.6
UTS	310 Mpa	Cr	0.04-0.35
Tensile Yield Strength	276 Mpa	Cu	0.15-0.4
Elongation at break	12%	Fe	Max 0.7

b.

Properties	Metric	Elements	Contents
Shear modulus	26 Gpa	Al	92.5-95
Elastic modulus	78-80 Gpa	Mg	4.5-5.5
Poisson’s ratio	0.33	Fe	0.4
-	-	Si	0.25

Figure 2: (a) The sample for current study (b) Preparation butt weld joint.

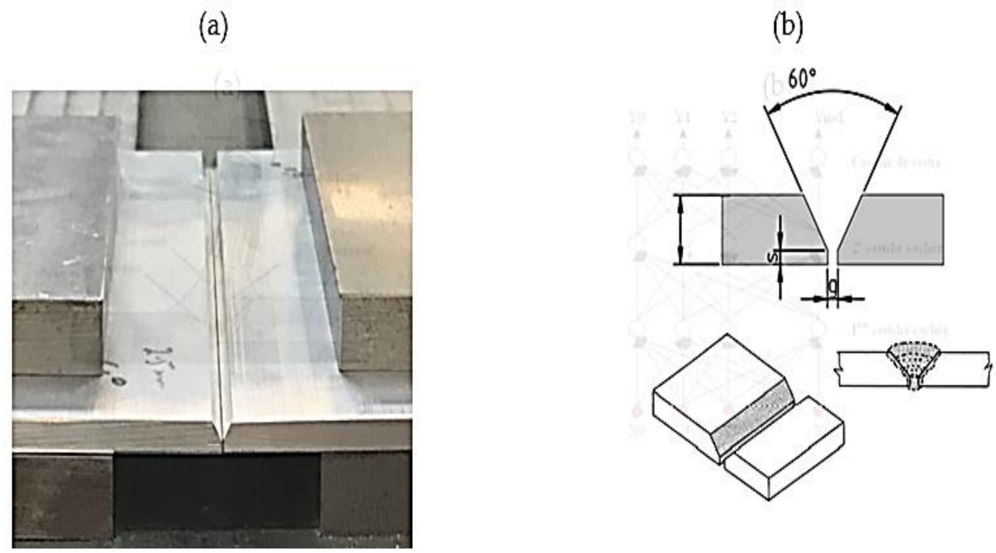


Figure 3: (a) Robot Fanuce R2000 (b) Miller Auto Axces 750 (c) Current welding process.

In this study, the preliminary Design of Experiments (DOE) is implemented based on the Taguchi method (Table 2). In fact, the consequences of the input parameters are being investigated. This is an L4 DOE that has been run with three input parameters and two levels to find the preliminary results. The input parameters are Voltage (V), Wire Feed Speed (WFS), and Distance from the nozzle to Weld (DISW). During the test, different gaps and different root faces were added. To find the better input parameters, 4 additional tests have been made and different root gaps and different root faces examined to get an acceptable result, at least better penetration (less lack of penetration), and better quality of the welds. Based on the results of the distortion of the first DOE, Artificial Neural Networks (ANNs) have been trained and the best parameters have been found. By using these results from the ANN model, the final DOE L8 has been created and the results for distortion have been measured (Table 3). To find better results, four additional tests have been developed and added to the final DOE. With a combination of both DOE, final test data has been created with 7 welding parameters such as Wire Feed Speed (WFS), Travel Speed (TS), Gun Angle (GA), Root Gap and Root Face, and finally Distance between nozzle and Weld (DISW). Based on test data, the final ANN model has been trained and the effect of the welding parameters on distortion has been found. (Table 2 shows a combination of both DOEs with additional tests.)(Table 4)

Table 2. Preliminary Design of Experiments and Error (DOE) with additional test.

	Test number	V input (V output)	DISW (mm)	WFS (mm/s)	Root Gap (mm)	Root Face(mm)
Preliminary DOE	1	19.2	12	161	0	2.5
	2	20.4	10	215	0	2.5
	3	22.8	12	215	0	2.5
	4	21.5	10	161	0	2.5
Additional tests	5	21.5	10	161	0.762	2.5
	6	21.5	10	161	1.143	2.5
	7	23.9	10	215	1.143	2.5
	8	23.9	10	215	0.381	1.5

Table 3. Final L8 DOE with additional test.

	Test number	V input (volt) (voltage output)	WFS(mm/s)	TS (mm/s)	GA(Degree)	GAP (mm)	ROOT (mm)	DISW (mm)
Final L8 DOE	9	20.4	204	10	10	0	1.5	10
	10	20.4	204	10	12	0.13	2.5	12
	11	20.9	225	12	10	0	2.5	12
	12	20.9	225	12	12	0.13	1.5	10
	13	23.05	204	12	10	0.13	1.5	12
	14	23.05	204	12	12	0	2.5	10
	15	23.6	225	10	10	0.13	2.5	10
	16	23.6	225	10	12	0	1.5	12
Additional tests	17	22.9	224	11	11	0.07	2	11
	18	23.9	225	11	11	0	2	11
	19	23.7	215	10	10	0	2.5	10
	20	23.5	225	10	10	0	2	10

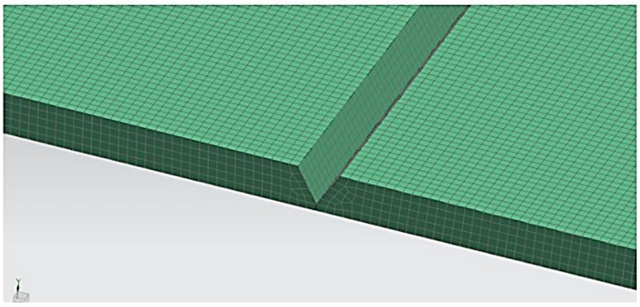
Table 4. Combination of both DOE with additional tests.

Test number	Voltage(v)	WFS (mm/s)	TS (mm/sec)	GA (degree)	Root Gap(mm)	Root Face(mm)	Current (A)	DISW (mm)
1	20.4	204	10	10	0	1.5	170	10
2	20.4	204	10	12	0.127	2.5	196	12
3	20.9	225	12	10	0	2.5	205	12
4	20.9	225	12	10	0.127	1.5	205	10
5	23.05	225	12	10	0.127	2.5	222	10
6	23.05	225	12	12	0	1.5	222	12
7	23.6	225	10	10	0.127	2.5	225	10
8	23.6	225	10	12	0	1.5	225	12
9	22.9	215	11	11	0.07	2	218	11
10	23.9	225	11	11	0	2	218	11
11	23.7	215	10	10	0	2.5	230	10
12	23.5	225	10	10	0	2	235	10
13	19.2	161	10	11	0	2.5	158	12
14	20.4	215	10	11	0	2.5	208	10
15	22.8	215	10	11	0	2.5	225	12
16	21.5	161	10	11	0	2.5	200	10
17	21.5	161	10	11	0.762	2.5	200	10
18	21.5	161	10	11	1.143	2.5	200	10
19	23.9	215	10	11	1.143	2.5	219	10
20	23.9	215	10	11	0.381	1.5	218	10

Finite Element Analysis

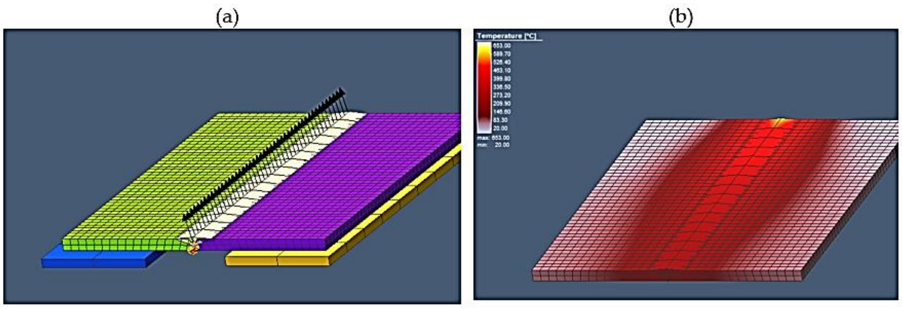
Geometry modelling: All test specimens with a 60-degree bevel angle, different root gaps, and different root faces in the weld zone are modelled, and the mesh is also created in NX. Figure 4 shows the mesh sample for one of the tests created in NX software. In this figure, the root face is 2.5 mm and the root gap is 0 mm.

Figure 4: Mesh sample from NX.



Simulation and analyses results: In this paper, Simufact welding simulation software is used to simulate the welding and analyze the distortion and deformation. This finite element software is used for the simulation analysis of the weldment and it is necessary to define the solver, boundary conditions, and heat resources, including welding parameters such as voltage, current, and travel speed, gun angle, the distance of the nozzle to the weld, as well as heat transfer coefficient parameters, and finally tracking of the welds. The solver is used with iterative sparse solver setting parameters including total simulation time, the respective flow time, time step, mesh refinement level, and the friction coefficient of the tracking point. From the Simufact software, the simulation was done with AL6061 T6, consisting of the same chemical composition as the Al6061 T6 in the model of the experiment (Table 1(a)). The process type is arc welding, the ambient temperature is 20°C, the components are two meshed samples converted from NX to Simufact, the fixings are two exactly the same geometry of the experiments and the acceleration due to gravity is 9.81 m/s^2. Figure 5 (a) shows samples with boundary conditions before starting solving and welding, and Figure 5 (b) shows thermal distribution after welds.

Figure 5: (a) Meshed sample with boundary condition (b) thermal distribution.



Analyses simulation results: All 21 samples have been modeled and simulated in the software and the results are shown in Table 3. In this table, distortion in each axis and total deformation measured from simulation, and results compared with experiments welded, the maximum error is 9.5% and the minimum error is 1.5% (Figure 6). Figure 7 shows the comparison of experiments and FEA of distortion. Just a quick explanation: The samples with errors of more than 10% are samples 2, 7, and 8. Sample 2 has a problem with the clamp, and samples 7 and 8 start and stop quickly during the weld. This is why the error is so big. (Table 5)

Figure 6. Distortion distribution (a) Minimum error test 17 (b) Maximum error test 8.

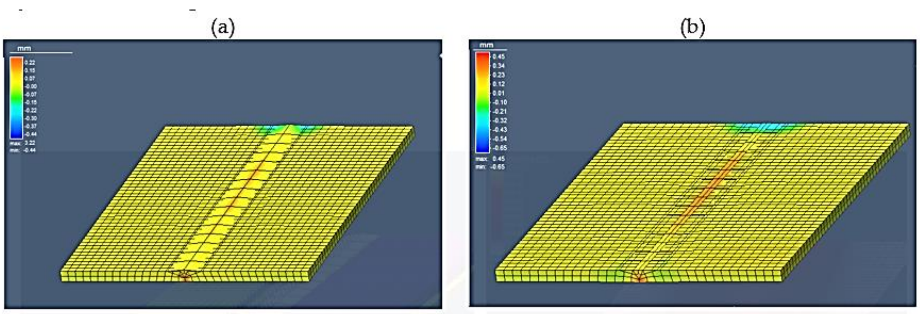


Figure 7. Comparison of experiments and FEA of distortion.

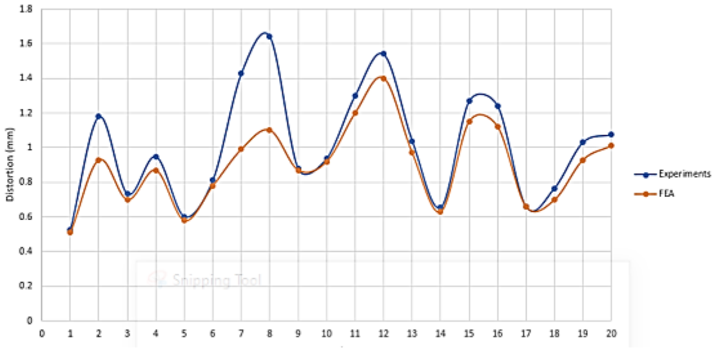


Table 5. Comparison of experiments and FEA of distortion

Test number	Experiments distortion	FEA distortion	Error %
1	0.5276	0.51	3.3
2	1.1786	0.93	21
3	0.7319	0.7	4.3
4	0.9486	0.87	8.2
5	0.6005	0.58	3.4
6	0.8112	0.78	3.8
7	1.4286	0.99	30
8	1.6422	1.1	33
9	0.8761	0.87	0.69
10	0.938	0.92	1.91
11	1.3016	1.2	7.8
12	1.54	1.4	9.09
13	1.039	0.97	6.6
14	0.6536	0.63	3.6
15	1.2686	1.15	9.3
16	1.2413	1.15	9.7
17	0.6581	0.66	0.28
18	0.7664	0.7	8.6
19	1.0313	0.93	9.8
20	1.0749	1.01	6.03

Study of models with varying parameters

Artificial neural network modeling: Due to their ability to learn and change on their own, Artificial Neural Network (ANN) models can create an impressive and identical mapping between input parameters and output variables [27]. In this search for the best ANN modeling factors, the effect of the input welding parameters on the accuracy of the neural network models is checked. Also, the accuracy of this method is checked by calculating the Root Mean Square Error (RMSE) and Max Error, which is the difference between the measured and estimated values of learning rate and momentum coefficient.

Figure 8 is a diagram of the structure of the Artificial Neural Network models, which have 7 inputs, 6 nodes in the hidden layer, and 1 output node. This is the process integration of Artificial Neural Network modeling for the effect of welding parameters on distortion. The second ANN model has been trained by putting together the results of both DOE's (Table 6). In the ANN model, data that has been learned and trained is used to make Table 6 for distortion with the least amount of error. Then, seven input parameters like voltage, wire feed speed, the distance between the nozzle and the weld, travel speed, root face, and root gap are used to implement the trained data. In short, Tables 4a and 4b show that the ANN models that were made to show how the welding process parameters affect distortion are reliable.

Figure 8. The architecture of ANN models in this paper.

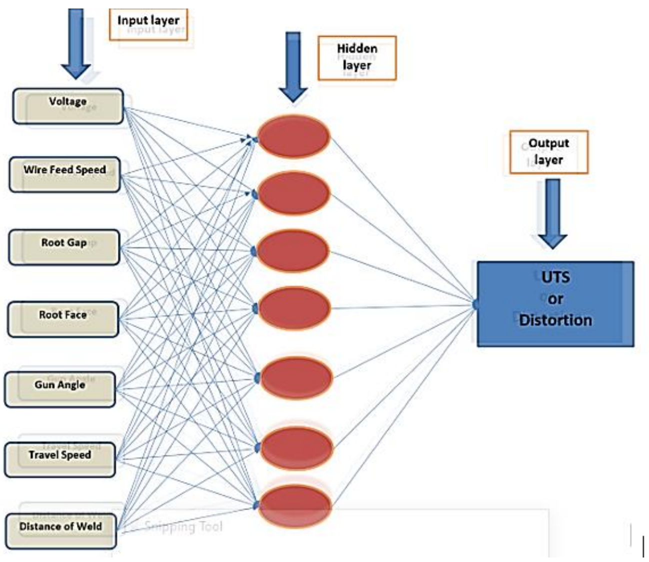


Table 6. The RMSE and maximum error for the (a) training data of Distortion (b) confirmation data.

(a)	
Distortion	
RMSE	Max Error
8.66E-09	8.76E-06

(b)	
Distortion	
RMSE	Max Error
2,70E-09	3,99E-05

RESULTS AND DISCUSSION

Effect of welding parameters process on distortion

Figure 6 shows the effect of voltage on distortion at different wire feed speeds and with other parameters changing. Based on the results, the following can be said:

1. Root gap Figure 9(a) 1 to 4:

- On all wire feed speeds, there is no effect of the variation in the gap between 0 and 0.17 (confirmed by experiments and FEA).
- At low wire feed speed, increasing voltage causes increased distortion.
- At a higher wire feed speed, minimum distortion is in the minimum voltage and maximum distortion is in the maximum voltage.

2. Root face Figure 9(b) 1 to 4:

- At high wire feed speeds (89 and 94 mm/s), there is no big effect of the variation at the root faces (confirmed by FEA).
- At low wire feed speeds (72 and 81 mm/s), maximum distortion happened at minimum voltage, and on all wire feed speeds, minimum distortion happened at minimum root face (1.5 mm).
- On voltage between 21 V and 23 V, for all wire feed speeds between 72 and 94 mm/s, the distortion is almost the same.

3. Distance of the weld Figure 9(c) 1 to 4:

- For voltage between 21 V and 23 V, for all types of wire feed speed (between 72 and 94 mm/s), there is no effect of the DISW (9 to 11 mm) on distortion (confirmed with experiments and FEA).
- For all wire feed speeds and DISW, minimum distortion happened at 23 V.
- At a wire feed speed of 89 mm/s, the variation of the distortion is the same for all DISW (confirmed with FEA).

4. Travel speed Figure 9(d) 1 to 4:

- On all high wire feed speeds (89 to 94 mm/s), by increasing the voltage, the range of the distortion is the same for all variations of the travel speed (confirmed by FEA).
- For all ranges of the wire feed speed and travel speed, minimum distortion almost happened on 23 V.
- At high wire feed speeds (89 to 94 mm/s), maximum distortion happened on 24 V (confirmed by FEA).

5. Gun angle Figure 9(e) 1 to 4:

- At all high wire feed speeds (89 to 94 mm/s), by increasing the voltage, the variation of the distortion is the same for all ranges of the gun angle (confirmed by FEA).

- Minimum distortion is on 23 V and gun angle 12 degrees for wire feed speeds ranging from 81 to 93 mm/s (confirmed by FEA).
- For the range of wire feed speed between 89 and 94 mm/s, maximum distortion is set at 24.5 V for all ranges of gun angle between 9 and 12 degrees.
- For almost all ranges of wire feed speed between 72 and 94 mm/s, the distortion on gun angle 12 degrees is less than the other ranges of gun angle and on gun angle 9 degrees is more than the other range of gun angle.

Figure 9: Distortion *vs*. voltage diagram for different wire feed speed with variation of the (a) Root gap (0-0.17mm) (b) Root face (1.5 to 2.5 mm) (c) Distance of the nozzle to weld (9 to 11 mm) (d) Travel speed (9 to 12 mm/s) (e) Gun angle (9 to 12 degree).

a	b	c	d	e
TS10,GA10,DISW10,RF1.5 (Gap0,0.125,0.15,0.17)	TS10,GAP 0.125, GA10,DISW10(RF1.5,2,2.5)	TS10,GA10,RF2.5,GAP0.125 (DISW9,10,11)	GA10,RF2.5,GAP0.125,DISW 10TS (9,10,11,12)	TS10,RF2.5,GAP0.125, DISW10 GA (9,10,11,12)

CONCLUSION

In the present research, the Gas Metal Arc Welding (GMAW) process was applied to make AA6061-T6 butt joints. The main goal of this paper is to evaluate the effect of the welding parameters such as voltage and wire feed speed on different travel speeds, root gap, root face, gun angle, and distance between the nozzle to weld on distortion. This study focused on the variation of the voltage and WFS and the effect of these on output parameters. The Taguchi method is used to minimize the number of experiments, and ANN modelling is implemented to anticipate the behaviour of the joints and parameters on output. Finally, a finite element analysis has been conducted to confirm the experiments and the ANN model. The following conclusions can be drawn from this research and investigation:

1. The wire feed speed, voltage, and travel speed are the factors that most influences the distortion.

2. The arc voltage is measured between the tip of the unmelted electrode and the surface of the weld pool. It depends in some part on the welder's technique. If the voltage is within the range indicated by an approved welding method, it should be possible to create acceptable welds. A convex and narrow bead results from having too low an arc voltage (short arc length) for a given current. In contrast, increased arc voltage (a longer arc) results in a larger, flatter bead with the potential for undercut, partial fusion, and heavy spatter. In practice, the arc voltage is the most important instrument for controlling the shape of the weld bead.

3. Experiments show, excessive travel speed (lower heat input) results in smaller, convex beads with restricted penetration and maybe undercut toes. However, if the travel speed is too slow, the arc force is absorbed by the molten weld pool rather than the base materials at the leading edge of the pool, resulting in a massive weld with limited penetration. When moving slowly through thinner materials, heat can build up and cause the material to melt through.

4. The distance between the nozzle and the work is the most crucial factor. For a particular voltage setting (arc length), an increase in distance increases electrode extension. The arc voltage decreases due to an increase in the voltage drop across the longer electrode extension, while the overall voltage remains constant due to the power source's constant voltage output. Both of these elements make the arc cooler and less penetrating.

FUNDING

This research has been supported by funds of PI2 Team.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

REFERENCES

1. Ryerson. 6061 Aluminum: Grade anatomy. 2020.
2. Saleem H, et al. Comprehensive materials processing. Elsevier. 2014.
3. Lathabai S. Fundamentals of aluminium metallurgy. Elsevier. 2011.
4. Shan X, et al. Thermo-mechanical modelling of a single-bead-on-plate element method. Inter Jl of Pres Vessels and Pip. 2009;86:110-121.

5. Smith M, et al. Residual stress analysis in linear friction welded in-service inconel 718 super alloy *via* neutron diffraction and contour method approaches. Mater Sci Engin. 2017;691:168-179.
6. Song S, et al. Residual stresses at weld repairs and effects of repair geometry. Sci and Tech of Weld and Join. 2017;22:265-277.
7. Sun T, et al. Comparison of residual stress distributions in conventional and stationary shoulder high-strength aluminum alloy friction stir welds. Jou of Mater Proce Tech. 2017;242:92-100.
8. Vemanaboinaa H, et al. Welding process simulation model for temperature and residual stress analysis. Inter Conf on Mater Procesand Charact. 2014;6:1539-1546.
9. Woo W, et al. Through-thickness distributions of residual stresses in two extreme heat-input thick welds: A neutron diffraction, contour method and deep hole drilling study. Acta Mater. 2013;61:3564-3574.
10. Nancy B. Statistical model to evaluate the weldability, mechanical and metallurgical properties of the processes GMAW and FCAW. Procee of the Wor Cong on Engin. 2014:2.
11. Surya S, et al. Optimisation of welding parameters of Flux Core Arc Welding (FCAW) of EN 24 & SS409 stainless steel for better tensile strength and hardness. Inter J of Tech Inno in Mod Engin & Sci. 2017:3.
12. Senthilkumar B. Influence of welding process parameters on bead geometry-A Review. J of Mecha and Mech Engin. 2017:1.
13. Slatineanu L, et al. Investigation on CO and microparticles concentrations produced in MAG-M welding process. App mech and mater jou. 2015.
14. Westin EM. Austenitic stainless steel bismuth-free flux-cored wires for high-temperature applications. Mater engine. 2016;60:1147-1158.
15. Jacek K. Diffusible hydrogen control in flux cored arc welding process. Key Engin mater. 2014;597:171-178.
16. Saket C, et al. Effect of welding parameters on microstructure and mechanical properties of friction stir welded Al 6061 aluminum alloy joints. Mater:Procc. 2019.
17. Yanning G, et al. Effect of welding parameter on dynamic fracture properties of 2024-T3 aluminum friction stir welded joints. Procedia Structural Integrity. 2018;13:806-812.
18. Park S, et al. Effects of the shoulder diameter and weld pitch on the tensile shear load in friction-stir welding of AA6111/AA5023 aluminum alloys. J of Mater Process Techn. 2017;241:112-119.
19. Lin H, et al. Effect of cooling conditions on microstructure and mechanical properties of friction stir welded 7055 aluminium alloy joints. Mate Charac. 2018;141:74-85.
20. Xia H, et al. Effect of heat input on a laser powder deposited Al/steel butt joint. Optics & Laser Technology. 2019;111:459-469.
21. Emine M, et al. Investigation on joint properties of AA5754 and AA6013 dissimilar aluminum alloys welded using automatic GMAW. Engin Scie and Techn. 2019.
22. Huang L, et al. Effect of the welding direction on the microstructural characterization in fiber laser-GMAW hybrid welding of 5083 aluminum alloy. J of Manu Proce. 2018;31:514-522.
23. Mizuno M, et al. Relations between restraint intensity and weld cracking in welding of aluminium alloy. Procee of the Third International Conference Aluminium-Verlag. 1985.
24. Sagatonovic K. Basic concepts of Artificial Neural Network (ANN) modeling and its application in pharmaceutical research. J of Pharm and Biom Anal. 2000;22:721-727.

25. Anand K. Artificial neural network modeling studies to predict the friction welding process parameters of Incoloy 800H joints. Engin Scie and Techn. 2015:654-670.
26. Chaitanya S, et al. Effect of welding parameters on microstructure and mechanical properties of friction stir welded joints of AA7039 aluminum alloy. Mater & Desi. 2015;36:1980-1988.
27. Yu B, et al. Driving rhythm method for driving comfort analysis on rural highways Promet Zagreb. TRID. 2014:371-379.