International Journal of Engineering Research and Modern Education (IJERME)
Impact Factor: 6.525, ISSN (Online): 2455 - 4200
(www.rdmodernresearch.com) Volume 2, Issue 2, 2017

AN EXPERIMENTAL INVESTIGATION ON WELDING BETWEEN MILD STEEL (AISI 1049) AND STAINLESS STEEL (AISI304) USING GTAW

Mohammad Nadeem Khalid* & M. Chithirai Pon Selvan**
Department of Mechanical Engineering, Amity University, Dubai,
United Arab Emirates

Cite This Article: Mohammad Nadeem Khalid & M. Chithirai Pon Selvan, "An Experimental Investigation on Welding Between Mild Steel (AISI 1049) and Stainless Steel (AISI304) Using GTAW", International Journal of Engineering Research and Modern Education, Volume 2, Issue 2, Page Number 20-27, 2017.

Abstract:

In this study dissimilar metals joints between stainless steel (SS-AISI 304) and mild steel (MS-AISI 1040) were joined by Gas Tungsten Arc Welding (GTAW). To systematically investigate the effects of the chosen process parameters (travel speed, current, gas flow rate, inclination) Taguchi's robust design of experiments was used. The experiments were performed using four parameters each varied at three levels based on the Taguchi's L_{18} orthogonal array. The weld quality was assessed by bead geometry response parameters and distortion. The results are optimized by means of Multi Objective Optimization by Ratio Analysis (MOORA) method. The bead geometry was analyzed in terms of weld bead reinforcement area, nugget area and heat effected zones in the stainless steel and mild steel regions. The results of MOORA revealed that the experiment consisting of travel speed gave the optimum value of the multi-response characteristic.

Key Words: TIG Welding, Travel Speed, Current, Gas Flow Rate, Angle of Inclination, Microstructure of Reinforcement Area, Nugget Area & Heat Affected Zone

Introduction:

Gas tungsten arc welding (GTAW), also known as tungsten inert gas (TIG) welding, is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmospheric contamination by an inert shielding gas (argon or helium), and a filler metal is normally used, though some welds, known as autogenous welds, do not require it. A constant-current welding power supply produces energy which is conducted across the arc through a column of highly ionized gas and metal vapors known as a plasma GTAW is most commonly used to weld thin sections of stainless steel and non-ferrous metals such as aluminum, magnesium, and copper alloys. The process grants the operator greater control over the weld than competing processes such as shielded metal arc welding and gas metal arc welding, allowing for stronger, higher quality welds. However, GTAW is comparatively more complex and difficult to master, and furthermore, it is significantly slower than most other welding techniques. A related process, plasma arc welding, uses a slightly different welding torch to create a more focused welding arc and as a result is often automated.[10]Basically tungsten inert gas welding is a contemporary method of welding which uses non-consumable tungsten electrode and an inert gas for arc shielding, is an extremely important arc welding process. Basically TIG is that type of welding process in which TIG weld quality is strongly characterized by the weld pool geometry. In this type of welding we use Taguchi method to determine the process parameter with the optimal weld pool geometry. This is because the Taguchi method is a systematic application of design and analysis of experiments for the purpose of designing and improving product quality [11, 12]. In recent years Taguchi method has become a powerful tool for improving productivity during research and development[13], so that high quality product can be produced quickly and at low cost. Welding of Austenitic Stainless steel has lot of applications in industries and manufacturing plants and these materials by the GTAW process and using Taguchi method to determine the process parameters with the optimal weld pool geometry. These materials have so many applications in aerospace, shipping, process industries and chemical industries etc. It is important to produce good and fine quality of product that's the reason GTAW process was chosen to understand the capability of producing good quality weld pool.

Existing Research Efforts and Objectives:

Jun Yan etal. [01] investigated the microstructure and mechanical properties of 304 stainless steel joints by tungsten inert gas (TIG) welding, laser welding and laser-TIG hybrid welding. The X-ray diffraction was used to analyze the phase composition, while the microscopy was conducted to study the microstructure characters of joints. Finally, tensile tests were performed and the fracture surfaces were analyzed. Kuang-Hung[02] Five kinds of oxide fluxes, MnO2, TiO2, MoO3, SiO2, and Al2O3, were used to investigate the effect of activated tungsten inert gas (activated TIG) process on weld morphology, angular distortion, delta-ferrite content, and hardness of Type 316L stainless steels. An autogenous TIG welding was applied to 6 mm thick stainless steel plates through a thin layer of flux to produce a bead-on-plate welded joint. The oxide fluxes used were packed in powdered form. The experimental results indicated that the SiO2flux facilitated root pass joint penetration, but Al2O3flux led to the deterioration in the weld depth and bead width compared with conventional TIG process. Del Coz Diaz et al.[03] In this study, thermal stress analyses were performed in the tungsten inert gas (TIG) welding process of two different stainless steel specimens in order to compare their distortion mode and magnitude. The growing presence of non-conventional stainless steel species like duplex family generates uncertainty about how their material properties could be affected under the welding process. To develop suitable welding numerical models, authors must consider the welding process parameters, geometrical constraints, material non-linearity and all physical phenomena involved in welding, both thermal and structural. In this sense, four different premises are taken into account. Butt et al.[04] GTAW (Gas Tungsten Arc Welding) process is one of the most significant processes of joining two or more pieces of the same or dissimilar materials to achieve complete coalescence using an inconsumable tungsten electrode. The present investigation is an attempt to study the variations in mechanical properties by both changing the base materials with respect to AISI 316 steel i.e. using SA516GR70 as well as annealing AISI 316 and SA 516GR70 plates initially and then welding to AISI 316. TIG welded AISI 316 with AISI 316 steel gives most moderate results to be used in required applications with least number of service limitations. Since UTS for TIG welded AISI 316-SA516 is higher than AISI 316-AISI 316 but it has a lower value of impact strength than AISI 316-AISI 316. Farahan et al.[05] The aim of this article is to evaluate the mechanical and microstructure properties of Inconel 617 weldments produced by direct current electrode negative (DCEN) gas tungsten arc welding (GTAW) and pulse current GTAW. In this regard, the micro structural examinations, impact test and hardness test were performed. The results indicated that the joints produced by direct mode GTAW exhibit poor mechanical properties due to presence of coarse grains and dendrites. Wan Ahmad Fitri Bin Johari [06]focusing on dissimilar joints metal by using TIG welding between dual phase steel and low carbon steel where only involve one type of joint that is square butt joint. Dissimilar joints metal between low carbon steel and dual phase steel is a common material that use in many industry, because the combination of this metal offer a good mechanical properties. However, welding joint is the weakest point in a component because most of the component failures occur at welding joints, so the purpose of this research is to investigate the failure analysis at that joint. Dinesh Rathodet al.[07] The main objective of present work was to study the micro-structural changes due to buttering deposit on AISI 1020 steel for dissimilar metal joint of AISI 1020 steel to SS 304 steel. Dissimilar metal joints are extensively used in many industrial applications but due to weldability related issues, they cannot perform satisfactory life. The difference in chemical composition, coefficient of thermal expansion and mechanical properties affects the weldability of the joint. For maintaining elemental compatibility, buttering technique is often used for such joint. It is quite difficult to select the consumables for the buttering layers, which will satisfy the requirement of desirable chemical composition. Carbon migration is one of the major causes for buttering layer deposits. Nickel act as a barrier for carbon migration, so paste technique was used to deposit the buttering layer. The paste was prepared with Nickel powder, Ferro-vanadium and Ferro-titanium powders and deposited using Tungsten Inert Gas (TIG) welding and Shielded Metal Arc (SMAW) welding. Subsequent layer deposit was made using SMAW using Inconel 182 consumables. Weld joint was prepared between said base metals using SMAW process and Metal Inert Gas (MIG) welding. Micro-structural analysis and micro-hardness analysis were carried out. Nickel rich paste layer deposited using TIG observed micro-cracks or solidification cracks. When deposited with SMAW, due to dilution effect, nickel composition reduced and ferrite content changes in buttering layer hence no any cracks observed. Nickel paste with controlled parameters with direct deposit using SMAW can be successfully applied for such dissimilar metal joints. Pasupathy [08] Tungsten Inert Gas welding (TIG) process is an important component in many industrial operations. The TIG welding parameters are the most important factors affecting the quality, productivity and cost of welding. This paper presents the influence of welding parameters like welding current, welding speed on strength of low carbon steel on AA1050 material during welding. A plan of experiments based on Taguchi technique has been used to acquire the data. An Orthogonal array, signal to noise (S/N) ratio and analysis of variance (ANOVA) are employed to investigate the welding characteristics of dissimilar joint and optimize the welding parameters. Finally the conformations tests have been carried out to compare the predicted values with the experimental values to confirm its effectiveness in the analysis of strength. Juang [09] the selection of process parameters for obtaining optimal weld pool geometry in the tungsten inert gas (TIG) welding of stainless steel is presented. Basically, the geometry of the weld pool has several quality characteristics, for example, the front height, front quality characteristics together in the selection of process parameters, the modified Taguchi method is adopted to analyze the effect of each welding process parameter on the weld pool geometry, and then to determine the process parameters with the optimal weld pool geometry. Experimental results are provided to illustrate the proposed approach. Width, back height and back width of the weld pool. To consider these quality characteristics together in the selection of process parameters, the modified Taguchi method is adopted to analyze the effect of each welding process parameter on the weld pool geometry, and then to determine the process parameters with the optimal weld pool geometry. Experimental results are provided to illustrate the proposed approach. Based on the above literature, the present study was conducted with the following objectives.

- ✓ To apply the GTAW process for joining dissimilar metals for (stainless steel and mild steel).
- ✓ To identify critical GTAW parameters that significantly affects the weld quality and develop process parameter window for successful welding of austenitic steels with mild steel.
- ✓ To perform experiments using the identified parameter range
- ✓ To investigate the effect of selected parameters on the mechanical property of weld, and also measure the welding force.

Methodology:

Austenitic steel grades Stainless steel-AISI 304 and mild steel-AISI 1040 played from jindal steels of 3mm thick were selected as base metal (B.M) for the experimentation. The specimens for experimentation were cut and machined in 1.5 inch wide and 5 inch long. After cutting the plates, all the specimens are finished by the 80 grit emery paper, for the purpose of oxide and other contaminants present on the top surface of the job. After finishing the finished operation the specimens are ready for the welding. Production of a quality GTAW weld requires proper machine material selection for the desired applications. The machine and the torch are subjected to severe stress and high temperature. So for the production of high quality of weld we select the Electra TIG machine and torch and the filler metal is of Stainless steel. The minimum and maximum range of machines are shown in table 1.

Table 1: Range of Parameters

Voltage Range	70 – 440 volts
Current Range	10 - 300 amps
Gas Flow Rate	5 – 40 l/min
Filler Wire Diameter	1.6 to 2.1 mm

Work Fixture Design for Inclination:

For the purpose of one of our parameter (inclination) we have to develop the fixture by which we can create the angle of inclination for the resting of specimen. So, we basically take 3 angles that is 4^0, 8^0, 12^0 what we did we make a fixture having 3 bases of 3 different angles. The fixture is made up of M.S which is shown in the figure below.

Figure 1: Fixture of Inclination

From the test trail, the following ranges are obtained as shown in table 2.

Table 2: Minimum and Maximum Suitable Range

Travel Speed	3.26 – 8.79 cm/min
Current	70 -150 amps
Gas Flow Rate	8 – 20 l/min
Angle of Inclination	3 – 14 degree

Determination Range of Process Parameters:

In order to determine the range of process parameters for performing GTAW welding with the help of indigenously designed fixture for inclination. An extensive literature survey was made from the literature survey it was found that researchers have used many GTAW parameters including travel speed, current, and gas flow rate for investigating different aspects of GTAW process. Based on the thorough literature review, extensive initial screening experiments were performed on 3 mm thick mild steel and Stainless steel plate. To determine the parameters that significantly affects the GTAW weld outputs. These screening experiments showed that in addition to the key process parameters namely travel speed, current, gas flow rate a number of other possible parameters such as NPD inclination also affects the various weld outputs and establishment of a defect free sound joint during the initial screening experiment results in many set back like over penetration, chattering, wide weld joint, dis-shaped weld bead. After screening the extensive trial experiments were performed to establish a process parameter window for the Stainless steel 304 and mild steel 1014 chosen for the research. It should be noted that the identified process window pushed the extreme of the four main input parameters but ensured that sound weld with clear and good surface finish. The GTAW welding process parameters used in the present work to explore the success of GTAW of Stainless steel 304 and mild steel 1040 are shown in figure below.

Table 3: GTAW Parameters and Levels

S.No	**Parameter**	**Symbol**	**Unit**	**Level 1**	**Level 2**	**Level 3**
1	Travel Speed	A	cm/min	4	8	8
2	Current	B	amps	75	100	125
3	Gas Flow Rate	C	l/min	10	14	18
4	Inclination	D	degree	4	4	12

Experimental Work:

Several experiments runs were performed used different combinations of process parameters shown in figure. Before welding every plat is cleaned, every experiment was performed after checking all the dimensions, tools and equipment's to avoid any error in the output result. Welding loads were recorded throughout the welding. After welding the weld specimen were visually inspected and if the weld bead was found acceptable then it is subjected to radiography to evaluate the soundness of joint

Table 4: Experimental layout using an L_{18} orthogonal array

S.No	Travel Speed	Current	Gas Flow Rate	Angle of Inclination
1	1	1	1	1
2	1	1	2	2
3	1	1	3	3
4	1	2	1	1
5	1	2	2	2
6	1	2	3	3
7	1	3	1	2
8	1	3	2	3
9	1	3	3	1
10	2	1	1	3
11	2	1	2	1
12	2	1	3	2
13	2	2	1	2
14	2	2	2	3
15	2	2	3	1
16	2	3	1	3
17	2	3	2	1
18	2	3	3	2

Figure 2: Weld Specimen

Cutting and Testing of Test Coupons:

The weld specimens were laid out to cut various test coupons for investigation of mechanical properties and microscopic test as per the plan. The test specimens were precisely machined using abrasive cutting machine. Test coupons were machined from the weld specimens and microscopic structure is done.

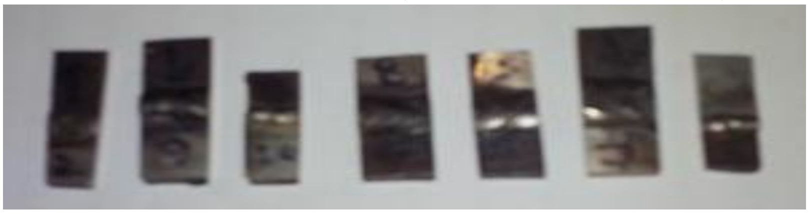


Figure 3: Test Specimens

Experiments as Per Orthogonal Array:

To select an appropriate orthogonal array for the experiments, the total degrees of freedom need to be computed. The degree of freedom are defined as the number of comparisons between design parameters that need to be made to determine which level is better and specifically how much better it is. For example, a three level design parameter counts for two degree of freedom. The product of the degree of freedom for two design parameters gives the degree of freedom associated with the interaction between the two design parameters. In the present study, the interactions between the GTAW parameters are neglected. Therefore, there are fifteen degrees of freedom owing there being three levels parameters in the GTAW process. Once the required degrees of freedom are known, the next step is to select an appropriate orthogonal array to fit the specific task. Basically, the degree of freedom for the orthogonal array should be greater than or at least equal to those for the design parameters. In this study, an L18 orthogonal array with four columns and eighteen rows was used. This array has seventeen degree of freedom and it can handle four design parameters. Each parameter is assigned to a column, eighteen parameters combination being available. Therefore only eighteen experiments are required to study the entire parameter space using the L18 orthogonal array. The experimental layout for the four parameters using orthogonal array is shown in Table-2. The experiments were performed according to the plan shown in Table-3.

Table 5: L_{18} Orthogonal Array with the Real Values of Parameters

Experiment No	Travel speed (cm/min)	Current (Amps)	Gas flow rate (l/min)	Angle of inclination (^{0})
1	4	75	10	4
2	4	75	14	8
3	4	75	18	12
4	4	100	10	4
5	4	100	14	8
6	4	100	18	12
7	4	125	10	8
8	4	125	14	12
9	4	125	18	4
10	8	75	10	12
11	8	75	14	4
12	8	75	18	8
13	8	100	10	8
14	8	100	14	12
15	8	100	18	4
16	8	125	10	12
17	8	125	14	4
18	8	125	18	8

Experiments as Per Plan:

Now after fixing the parameters and their levels the experiment is carried out as per plan using the L_{18} orthogonal array, 18 numbers of plates of Mild steel and Stainless steel are Butt welded together by using GTAW process. After the welding the plates are cut to 5mm strip from where the bead of weld is of good quality. After cutting the strips of 5mm, these strips were grinded and then polished (mirror like). This polishing is done by using emery paper of different grades (i.e. No.100- No.1000). Then after polishing, the polished surface has been etched by a reagent named Kalling Solution, its chemical composition is as follows.

Table 6: Chemical Composition for Etching

S.No	Chemical Compound	Quantity
1	$CuCl_2$	5gm
2	Hcl	100ml
3	Ethanol	100ml

When the etching is done the specimen are viewed in the microscope to find the extent of Heat affected zone (HAZ) in both plates welded i.e. Stainless steel and mild steel Along with the HAZ the reinforcement area and the nugget area has also been calculated by the software called caliber pro.The responses that are being measured in this experiment are as follows.

- ✓ Reinforcement Area
- ✓ Nugget Area
- ✓ Heat affected zone (HAZ) area of Mild steel (MS).
- ✓ Heat affected zone of (HAZ) area of Stainless steel (S.S)

Results and Discussions:

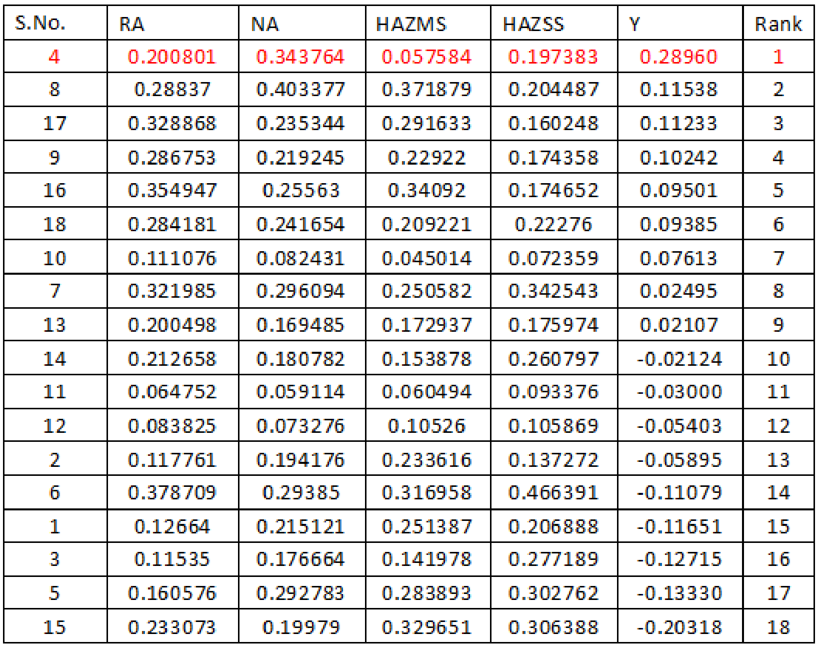
Optimization of Process Parameters:

All the response of the 18 experiments was measured and is shown in table 7. By applying “Multi-objective optimization on the basis of Ratio analysis (MOORA) method on the collected data, the normalized decision making table is prepared. The value of Yi is then sorted from greatest value to lowest value. The highest value shows the rank one and the lowest value gives the last rank. As it can be seen, 4thexperiment has the greatest value of Yi which tells us that it has Rank ONE among the 18 experiments.

Table 7: Objective data from the attributes

S.No	A	B	C	D	RA	NA	HAZMS	HAZSS
1	4	75	10	4	92749.307	233012.465	28116.343	29245.152
2	4	75	14	8	86246.537	210325.485	26128.809	19404.432
3	4	75	18	12	84480.609	191357.341	15879.501	39182.852
4	4	100	10	4	147063.712	372354.571	6440.443	27901.662
5	4	100	14	8	117603.878	317132.964	31752.078	42797.784
6	4	100	18	12	277361.496	318289.474	35450.139	65927.978
7	4	125	10	8	235817.175	320720.222	28026.316	48421.053
8	4	125	14	12	211198.061	436925.208	41592.798	28905.817
9	4	125	18	4	210013.85	237479.224	25637.119	24646.814
10	8	75	10	12	81350.416	89286.704	5034.626	10228.532
11	8	75	14	4	47423.823	64030.471	6765.928	12199.446
12	8	75	18	8	61391.967	79369.806	11772.853	14965.374
13	8	100	10	8	146842.105	183580.332	19342.105	24875.346
14	8	100	14	12	155747.922	195817.175	17210.526	36865.651
15	8	100	18	4	170699.446	216405.817	36869.860	43310.249
16	8	125	10	12	259958.449	276890.58	38130.194	24688.366
17	8	125	14	4	240858.726	254916.898	32617.729	22652.355
18	8	125	18	8	208130.194	261752.07	23400.277	31488.92
					5.3639E+11	1.1733E+12	1.251E+10	1.998E+10
					732386.209	1083168.73	111845.04	141357.74

Table 8: Normalized decision making matrix and result of multi objective analysis



S.No.	RA	NA	HAZMS	HAZSS	Y	Rank
4	0.200801	0.343764	0.057584	0.197383	0.28960	1
8	0.28837	0.403377	0.371879	0.204487	0.11538	2
17	0.328868	0.235344	0.291633	0.160248	0.11233	3
9	0.286753	0.219245	0.22922	0.174358	0.10242	4
16	0.354947	0.25563	0.34092	0.174652	0.09501	5
18	0.284181	0.241654	0.209221	0.22276	0.09385	6
10	0.111076	0.082431	0.045014	0.072359	0.07613	7
7	0.321985	0.296094	0.250582	0.342543	0.02495	8
13	0.200498	0.169485	0.172937	0.175974	0.02107	9
14	0.212658	0.180782	0.153878	0.260797	-0.02124	10
11	0.064752	0.059114	0.060494	0.093376	-0.03000	11
12	0.083825	0.073276	0.10526	0.105869	-0.05403	12
2	0.117761	0.194176	0.233616	0.137272	-0.05895	13
6	0.378709	0.29385	0.316958	0.466391	-0.11079	14
1	0.12664	0.215121	0.251387	0.206888	-0.11651	15
3	0.11535	0.176664	0.141978	0.277189	-0.12715	16
5	0.160576	0.292783	0.283893	0.302762	-0.13330	17
15	0.233073	0.19979	0.329651	0.306388	-0.20318	18

Table 9: Optimum Results

Optimum result A1B2C1D1	
Travel speed	4cm/min
Current	100 amps.
Gas flow rate	10 l/min
Angle of inclination	4 degrees

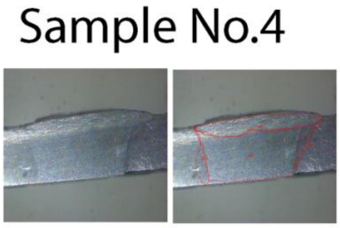


Figure 4: Photograph of Sample 4

Conclusions and Scope of Future Work:

This experiment shows that the parameter i.e. “inclination of plate” can be used to join two dissimilar metals. Because researchers have done the buttering technique of Inconel metal on steel and then after weld these two materials. Does this to prevent stainless steel from contamination with mild steel contain large amount of carbon as compared to stainless steel. By doing inclination of plate and putting stainless steel plate on top the arc length get shorter in Stainless steel and have high temperature and melts Stainless steel faster and due to inclination gravity pull the molten pool downwards and prevents Stainless steel to get contaminated from mild steel.In future similar study can be done in which instead of microstructure the following tests can be performed Tensile testing, Distortion, Surface roughness, Hardness etc. And for analysis of data instead of using MOORA method the following methods can be applied Analysis of means, Analysis of variance method, Grey relational analysis. Same experiments can be done for optimization of other welding process such as Arc welding, GMAW, Submerged arc welding, Laser welding, Friction stir welding etc. In future work the process parameters that have been taken in this project can be changed to other parameters like current and voltage and different filler material can be used such as mild steel wire pool.

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