Experimental Analysis and Optimization of Weld Characteristics and Bead Geomtery Analysis for Stainless Steel 409 by GMAW Process

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Abstract – Quality and productivity play important role in today's manufacturing market. Now a day's due to very stiff and cut throat competitive market condition in manufacturing industries. The main objective of industries reveals with producing better quality product at minimum cost and increase productivity. Welding is the most vital and common operation use for joining of two similar and dissimilar parts. In the present research work an attempt is made to understand various welding techniques and to find the best welding technique for steel. Special focuses have been put MIG welding. On hardness testing machine and UTM various characteristics such as strength, hardness, Tensile strength were analyzed. In our experiment we found out the input parameter value 160 AMPS VOLT-22,STAND OFF DISTANCE 2.5 were the best value and it does not create any major changes and failures in the testing process. The tensile strength value was higher value obtained 160 AMPS VOLT-22, STAND OFF DISTANCE 2.5 on that parameter of the testing plate. According to the Taguchis design and optimized parameter were hardness and Tensile strength value for the 5 mm plate of SS409 steel is 140 AMPS VOLT-24,STAND OFF DISTANCE 3.0MM.

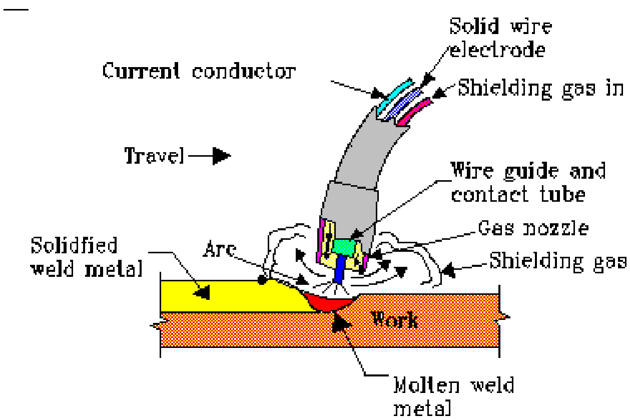
Index Terms – Martensiticstainless steel; hardness; tensile strength and HAZ.

1. INTRODUCTION

1.1 MIG welding

Advantage Fabricated Metals performs a number of welding processes. The two most common welding processes we use include TIG, an acronym for Tungsten Inert Gas welding and MIG, an acronym for Metal Inert Gas welding. TIG is also referred to as GTAW (Gas Tungsten Arc Welding) and Heliarc®. MIG also is referred to as GMAW (Gas Metal Arc Welding). We also provide oxy-acetylene welding.

The "Metal" in Gas Metal Arc Welding refers to the wire that is used to start the arc. It is shielded by inert gas and the feeding wire also acts as the filler rod. MIG is fairly easy to learn and use as it is a semi-automatic welding process.



1.2. Applications

1. The process can be used for the welding of carbon, silicon and low alloy steels, stainless steels, aluminum, magnesium, copper, nickel, and their alloys, titanium, etc.
2. For welding tool steels and dies.
3. For the manufacture of refrigerator parts.

4. MIG welding has been used successfully in industries like aircraft, automobile, pressure vessel, and ship building.

2. LITERATURE REVIEW

Vedprakash Singh, [et al] 1 Gas tungsten arc welding is a fusion welding process having wide applications in industry. In this process proper selection of input welding parameters is necessary in order to control weld distortion and subsequently increase the productivity of the process. In order to obtain a good quality weld and control weld distortion, it is therefore, necessary to control the input welding parameters. In this research work, experiments were carried out on Austenitic stainless steel 304 plates of 5mm thick using gas tungsten arc welding (GTAW) process. Full Factorial method is used to formulate the experimental design. The exhaustive survey suggests that some control factors viz. current, welding speed, Groove etc. predominantly influence the weld distortion. A plan of experiments based on full factorial technique has been used to acquire the data. An analysis of variance (ANOVA) is employed to investigate the welding characteristics of Austenitic stainless steel 304 material & optimize the welding parameters. Furthermore, output obtained through multiple regression analysis is used to compare with the developed artificial neural network (ANN) model output. It was found that the welding strength predicted by the developed ANN model is better than that based on multiple regression analysis.

Radha Raman Mishra, [et al] 2 The dissimilar metal joints of have been emerged as a structural material for various industrial applications which provides good combination of mechanical properties like strength, corrosion resistance with lower cost. Selections of joining process for such a material are difficult because of their physical and chemical properties. The stainless steel and mild steel dissimilar material joints are very common structural applications joining of stainless steel and mild steel is very critical because of carbon precipitation and loss of chromium leads to increase in porosity affects the quality of joint leads deteriorate strength. In the present study, stainless steel of grades 202, 304, 310 and 316 were welded with mild steel by Tungsten Inert Gas (TIG) and Metal Inert Gas (MIG) welding processes. The percentage dilutions of joints were calculated and tensile strength of dissimilar metal joints was investigated. The results were compared for different joints made by TIG and MIG welding processes and it was observed that TIG welded dissimilar metal joints have better physical properties than MIG welded joints.

Mohit Singhmar,[et.al] 3 The objective of this research was to study influenceparameters affecting to mechanical property of austenitic stainless steel grade 304 (AISI 304) with Gas Metal Arc Welding (GMAW). The research was applying Taguchi Method on anaustenitic stainless steel specimen of dimensions 110 × 40 × 3 mm, which have following interested parameters: arc current at 150, 200, and 250 Amps, gas flow rate at 10, 20, and 30 kg/hr and arc voltage at 15, 20 and 25 Volt.The study was done in following aspects: Ultimate tensile strength. The present paper aims at the study of factors affecting tomechanical property of austenitic stainless steel with Gas Metal Arc Welding (GMAW) at different welding parameters.

Pawan Kumar, [et al] 4 Welding is widely used by manufacturing engineers and production personnel to quickly and effectively set up manufacturing processes for new products. This study discusses an investigation into the use of Taguchi's Parameter Design methodology for Parametric Study of Gas Metal Arc Welding of Stainless Steel & Low Carbon Steel. In this research work, bead on plate welds were carried out on AISI 304 & Low Carbon Steel plates using gas metal arc welding (GMAW) process. Taguchi method is used to formulate the experimental design. Design of experiments using orthogonal array is employed to develop the weldments. The input process variables considered here include welding current, welding voltage & gas flow rate. A total no of 9 experimental runs were conducted using an L9 orthogonal array, and the ideal combination of controllable factor levels was determined for the hardness to calculate the signal-to-noise ratio. After collecting the data signal-to-noise (S/N) ratios were calculated and used in order to obtain optimum levels for every input parameter. Subsequently, using analysis of variance (ANOVA) the significant coefficients for each input parameter on tensile strength & Hardness (PM, WZ & HAZ) were determined and validated.

Mr.L.Suresh Kumar,[et al] 6 ustenitic stainless steel for the process of TIG and MIG welding. As with other welding processes such as gas metal arc welding, shielding gases are necessary in GTAW or MIG welding is used to protect the welding area from atmospheric gases such as nitrogen and oxygen, which can cause fusion defects, porosity, and weld metal embitterment if they come in contact with the electrode, the arc, or the welding metal. The gas also transfers heat from the tungsten electrode to the metal, and it helps start and maintain a stable arc. We used the TIG and MIG process to find out the characteristics of the metal after it is welded .The voltage is taken constant and various characteristics such as strength, hardness, ductility, grain structure, modulus of elasticity, tensile strength breaking point, HAZ are observed in two processes and analyzed and finally concluded.

M. Balasubramanian, [et al] 7 Mechanical strength of the weldments is not only influenced by the composition of the metals but selection of process parameters and weld bead profile also play a vital role in determining the strength. The relationships between the process parameters and the bead parameters controlling the bead shape are to be established. This is achieved by the development of mathematical expressions, relating the weld bead dimensions to the important process control variables affecting these dimensions. Also, optimization of the process parameters to control and obtain the required shape and quality of weld beads is also made possible with these expressions. The pulsing current parameters on weld pool geometry namely front height, back height, front width and back width of pulsed current tungsten inert gas welding (PCTIG) of titanium alloy was analyzed. Box–Behnken design was used to develop empirical relationships, incorporating pulsed current parameters and weld pool geometry.

3. PROBLEM IDENTIFICATION AND DEFINITION

The range of applications of austenitic stainless steel includes house wares, containers, industrial piping and vessels, architectural facades and constructional structures. When welding stainless steels it is adviaisable to follow the general welding guidelines valid for the type of steel, e.g. austenitic Stainless steels have, due to their chemical compositions, a higher thermal elongation compared to mild steels. This may increase weld deformation. Dependent of weld metal microstructure they might also be more sensitive to hot cracking and sensitive to intermetallic precipitations compared to mild steels. Austenitic grades are those alloys which are commonly in use for stainless applications. The austenitic grades are not magnetic. The most common austenitic alloys are ironchromium- nickel steels and are widely known as the 300 series. The austenitic stainless steels, because of their high chromium and nickel content, are the most corrosion resistant of the stainless group providing unusually fine mechanical properties. They cannot be hardened by heat treatment, but can be hardened significantly by cold-working. The special material properties of stainless steels affect all four mach inability factors: in general, it can be said that the higher the alloy content of a stainless steel, the more difficult it is to machine. The special properties that make stainless steels difficult to machine occur to a greater or lesser extent in all grades of stainless steels, but are most marked in the austenitic grades. They can be summarized in five points:

1. Stainless steels work-harden considerably
2. Stainless steels have low thermal conductivity
3. Stainless steels have high toughness
4. Stainless steels tend to be sticky
5. Stainless steels have poor chip-breaking characteristics.

3.1. Scope of Work

In this work, of first a detailed study of MIG Welding and process parameters are made. Then problems in welding of Austenitic stainless steel with ferritic and martensitic stainless steel using conventional Welding process are analyzed. In the next phase design of Experiment are done by conducting several Welding in the test specimens and the effect of each parameters and depth of penetration is analyzed.

4. MATERIAL USED

4.1 SS 409

Grade 409is the basic martensitic stainless steel; like most non-stainless steels it can be hardened by a "quench-and-temper" heat treatment. It contains a minimum of 11.5 per cent chromium, just sufficient to give corrosion resistance properties. It achieves maximum corrosion resistance when it has been hardened and tempered and then polished. Grade 409 is a general purpose grade often supplied in the hardened, but still machinable condition, for applications where high strength and moderate heat and corrosion resistance are required.

Martensitic stainless steels are optimised for high hardness, and other properties are to some degree compromised. Fabrication must be by methods that allow for poor weldability and usually the need for a final heat treatment. Corrosion resistance of the martensitic grades is lower than that of the common austenitic grades, and their useful operating temperature range is limited by their loss of ductility at sub-zero temperatures and loss of strength by over-tempering at elevated temperatures.

4.1.1Composition

Typical compositional ranges for grade 409 stainless steels are given

Table 4.1Composition ranges for 409 grade stainless steel

Grade		C	Mn	Si	P	S	Cr	Mo	Ni	N
409	min.	-	-	-	-	-	11.5	-	0.75	-
	max.	0.15	1.00	1.00	0.040	0.030	13.5			

4.1.2. MIG Welding Machine Specification

MIG Welding Machine

Size of Filler Rod : 2mm

Filler Rod Material : Copper Coated Mild Steel

Ampere Rating :20-500 Amps

Machine : SUNPOWER

5. EXPERIMENTAL ANALYSIS

5.1. Welding Input Parameter

AMPERE **Amps**	**VOLTAGE** **volt**	**STRIKE OFF DISTANCE** **mm**
140	22	2.0
140	24	2.5
140	26	3.0
160	22	2.5
160	24	3.0
160	26	2.0
180	22	3.0
180	24	2.0
180	26	2.5

6. EXPERIMENTAL ANALYSIS

6.1. Hardness Test

ROCKWELL HARDNESS TEST VALUE OF BEFORE WELDING

Table 6.1. Hardness Value of Before Welding

Load-100kgf Indenter-Ball indenter

Table 7.1 Hardness Value of Before Welding

MATERIAL	**HARDNESS VALUE-HRB**
SS409	65

Hardnss Test Value Of After Welding

Table 6.2 Hardness Value of Before Welding

Materials	TEST PLATE	AVG HRB
SS409	S1	71

	S2	68
	S3	69
	S4	**65**
	S5	67
	S6	68
	S7	70
	S8	72
	S9	75

6.2. Tensile Test

6.2.1. Introduction of Tensile Test

A tensile test, also known as tension test is probably the most fundamental type of mechanical test you can perform on material. Tensile tests are simple, relatively inexpensive, and fully standardized. By pulling on something , you will very quickly determine how the material will react to forces being pulled, you will find its strength along with how much it will elongate .

6.2.2. Test Particulars

Description : Welding plate – 01 No
Material Specification : SS 409
Plate Thickness : 5mm
Welding Process : MIG
Identifications : T1-T9

6.3. Test Result

Table 6.2: Transverse Tensile Test

	Width*Thickness	**Area MM2**	**T. Load(N)**	**Tensile Strength MPA**
T1	31.78*5.22	165.89	78400	473
T2	31.88*5.40	172.15	66000	383
T3	31.30*5.34	167.14	46000	275
T4	**31.42*5.30**	**166.53**	**81000**	**486**
T5	31.10*5.36	166.70	68000	408
T6	31.42*5.38	169.04	77800	460
T7	31.38*5.32	166.94	67000	401
T8	31.62*5.42	171.38	81000	473
T9	31.60*5.40	170.64	79400	465

7. EXPERIMENTAL DESIGN

7.1. Taguchi Design

Basically, experimental design methods were developed original fisher. However experimental design methods are too complex and not easy to use. Furthermore, a large number of experiments have to be carried out when the number of the process parameters increases, to solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. The experimental results are then transformed into a signal – to – noise (S/N) ratio to measure the quality characteristics deviating from the desired values. Usually, there are three categories of quality characteristics in the analysis of the S/N ratio, i.e., the – lower – better, the – higher – better, and the – nominal – better. The S/N ratio for each level of process parameter is compared based on the S/N analysis. Regardless of the category of the quality characteristic, a greater S/N ratio corresponds to better quality characteristics. Therefore, the optimal level of the process parameters is the level with the greatest S/N ratio Furthermore, a statistically significant with the S/N and ANOVA[3] analyses, the optimal combination of the process parameters can be predicted. Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the parameter design. There are 3 Signal-to-Noise ratios of common interest for optimization of Static Problems. The formulae for signal to noise ratio are designed so that an experimenter can always select the largest factor level setting to optimize the quality characteristic of an experiment. Therefore a method of calculating the Signal-To-Noise ratio we had gone for quality characteristic. They are

1. Smaller-The-Better,
2. Larger-The-Better,
3. Nominal is Best.

7.2. Design of Experiment

Table 7.1: Process parameters and their levels responses for all noise factors for the given factor level combination

Levels	**Process parameters**		
	AMPS	**VOLT**	**STAND OFF DIST**
1	140	22	2.0
2	160	24	2.5
3	180	26	3.0

7.3. Hardness (Analysis of Result)

Table 7.2 S/N ratios values for the Hardness

T.NO	**Designation**	**AMPS**	**VOLT**	**Stand of dist mm**	**HARDNESS**	**SNRA1**
1	$A_1B_1C_1$	140	22	2.0	71	-37.0252
2	$A_1B_2C_2$	140	24	2.5	68	-36.6502
3	$A_1B_3C_3$	140	26	3.0	69	-36.7770
4	$A_2B_1C_2$	160	22	2.5	65	-36.2583
5	$A_2B_2C_3$	160	24	3.0	67	-36.5215
6	$A_2B_3C_1$	160	26	2.0	68	-36.6502
7	$A_3B_1C_3$	180	22	3.0	70	-36.9020
8	$A_3B_2C_1$	180	24	2.0	72	-37.1466

9	$A_3B_3C_2$	180	26	2.5	75	-37.5012

7.4. Taguchi Analysis: HARD versus AMPS, VOLT, GP

Table 7.3: Response Table for Signal to Noise Ratios; Smaller is better

Level	**AMPS**	**VOLT**	**STD**
1	-36.82	-36.73	-36.94
2	-36.48	-36.77	-36.80
3	-37.18	-36.98	-36.73
Delta	0.71	0.25	0.21
Rank	1	2	3

Table 7.4: Analysis of Variance for HARD, using Adjusted SS for Tests

Source	**DF**	**SEQ SS**	**ADJ SS**	**ADJ SS**	**F**	**P**	**% of Contribution**
AMPS	2	48.222	48.222	24.111	4.43	0.184	68.67
VOLT	2	6.889	6.889	3.444	0.63	0.613	10
STD	2	4.222	4.222	2.111	0.39	0.721	6
ERROR	2	10.889	10.889	5.444			16
TOTAL	8	70.222					100

S = 2.33333 R-Sq = 84.49% R-Sq(adj) = 37.97%

7.4. Taguchi Optimization through Minitab -16

Tensile Load (Analysis of Result)

Table 7.5: S/N ratios values for the Tensile load

T.No.	Designation	AMPS	VOLT	Stand of dist mm	Tensile Load KN	SNRA1
1	$A_1B_1C_1$	140	22	2.0	78.4	37.8863
2	$A_1B_2C_2$	140	24	2.5	66.0	36.3909
3	$A_1B_3C_3$	140	26	3.0	46.0	33.2552
4	$A_2B_1C_2$	160	22	2.5	81.0	38.1697
5	$A_2B_2C_3$	160	24	3.0	68.0	36.6502

6	$A_2B_3C_1$	160	26	2.0	77.8	37.8196
7	$A_3B_1C_3$	180	22	3.0	67.0	36.5215
8	$A_3B_2C_1$	180	24	2.0	81.0	38.1697
9	$A_3B_3C_2$	180	26	2.5	79.4	37.9964

Table 7.6: Taguchi Analysis: HARD versus AMPS, VOLT, GP

Response Table for Signal to Noise Ratios

Smaller is better

Level	AMPS	VOLT	GP
1	-36.82	-36.73	-36.94
2	-36.48	-36.77	-36.80
3	-37.18	-36.98	-36.73
Delta	0.71	0.25	0.21
Rank	1	2	3

Table 7.7: Analysis of Variance for HARD, using Adjusted SS for Tests

SOURCE	DF	SEQ SS	ADJ SS	ADJ SS	F	P	% of Contribution
AMPS	2	299.37	299.37	149.68	4.90	0.169	28
VOLT	2	89.72	89.72	44.86	1.47	0.405	9
STD	2	592.92	592.92	296.46	9.71	0.093	56
ERROR	2	61.08	61.08	30.54			7
TOTAL	8	1043.08					100

S = 2.33333 R-Sq = 84.49% R-Sq(adj) = 37.97%

8. ULTRASONIC RESULT

8.1. Specification

UT instrument : PX 20

Transducer angle : 70º 4 MHZ

Technique : pulse Echo

Size : 8 x 9

Material : 409

Thickness : 12MM

8.2. Ultrasonic Test Report

Table.8.1 Ultrasonic Report

S.No	**AMPS**	**VOLT**	**STD**	**Indications**
1.	140	22	2.0	ICP &Por
2.	140	24	2.5	ICP
3.	140	26	3.0	ICP &Por
4.	**160**	**22**	**2.5**	**NI**
5.	160	24	3.0	EP
6.	160	26	2.0	EP
7	180	22	3.0	Sl
8	180	24	2.0	Cr
9	180	26	2.5	Cr

9. DEPTH OF PENETRATION

Inadequate weld bead dimensions such as shallow depth of penetration may contribute to failure of a welded structure since penetration determines the stress carrying capacity of a welded joint .To avoid such occurrences the input or welding process variables which influence the weld bead penetration must therefore be properly selected and optimized to obtain an acceptable weld bead penetration and hence a high quality joint . To predict the effect of welding process variables on weld bead geometry and hence quality researchers have employed different techniques.

9.1. Various Sizes of Bead Width, Depth of Penetration

SAMPLES	Area	Mean	Min	Max	Angle	Length
	1.15	151.098	67	171.979	179.594	22.029
1	0.556	142.182	67	174.882	90.843	10.625
	0.914	139.273	57.119	177.696	-2.556	17.515
2	0.377	150.585	46.797	193.399	86.269	7.202
	1.313	157.588	55	188.387	-0.356	25.154
3	0.464	127.018	30	169.667	90	8.905
	0.93	**119.02**	**45**	**154.526**	**178.493**	**17.816**
4	**0.589**	**107.135**	**20.667**	**160**	**90.796**	**11.25**
	1.066	152.252	93	173	180	20.466
5	0.423	134.541	33	172.667	90	8.124

	0.93	125.566	42.053	164.263	-0.503	17.811
6	0.377	128.763	37.159	172.797	87.51	7.193
	0.995	158.366	125	174.492	-179.53	19.061
7	0.496	155.528	75	178.333	90	9.53
	1.223	119.485	49.8	176.889	0.382	23.435
8	0.491	124.307	22.8	189	88.091	9.379
	0.946	156.193	69.057	195.345	-1.975	18.134
9	0.328	140.061	57.583	184.267	88.568	6.251

10. RESULT & CONCLUSION

MIG welding can be used successfully to join SS409. The processed joints exhibited better mechanical and metallurgical characteristics. The joints exhibited 90-95% of parent material's Hardness value. The specimen failures were associated depending upon the improper changes of heat value. It creates so many metallurgical defects and it is identified by using NDT testing. In our experiment we found out the input parameter value 160 AMPS VOLT-22,STAND OFF DISTANCE 2.5) is the best value and it does not create any major changes and failures in the testing process. The tensile strength r value is higher (160 AMPS VOLT-22, STAND OFF DISTANCE 2.5) than other value.. According to the Taguchis design and optimized parameter is hardness and Tensile strength value for the 5 mm plate of SS409 steel is 140 AMPS VOLT-24,STAND OFF DISTANCE 3.0MM .

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