Scientific Journal of Impact Factor (SJIF): 3.134
ISSN (Online): 2348-4470
ISSN (Print) : 2348-6406

International Journal of Advance Engineering and Research Development

Volume 2, Issue 1, January -2015

EXPERIMENTAL STUDY FOR WELDING ASPECTS OF AUSTENITIC STAINLESS STEEL (AISI 304) ON HARDNESS BY TAGUCHI TECHNIQUE

Mohit Singhmar#1, NishantVerma#2

Student M.tech., Om Institute of Technology and Management, Hisar,Haryana,India
Assistant Prof. Department of Mechanical Engineering, Om Institute of Technology and Management, Hisar,Haryana,India
E-mail: [1]mohitsinghmar05@gmail.com
[2]nishantverma111@gmail.com

Abstract: 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 aaustenitic stainless steel (304) 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: Hardness of Heat affected zone and Weld bead.

The present paper aims at the study of factors affecting to mechanical property of austenitic stainless steel with Gas Metal Arc Welding (GMAW) at different welding parameters.

Keywords-- Austenitic Stainless Steel (AISI 304), Taguchi method,Hardness.

I. INTRODUCTION

Gas Metal Arc Welding is one of the most widely used processes in industry. The input parameters play a very significant role in determining the quality of a welded joint. In fact, weld geometry directly affects the complexity of weld schedules and thereby the construction and manufacturing costs of steel structures and Mechanical devices. Therefore, these parameters affecting the arc and welding should be estimated and their changing conditions during process must be known before in order to obtain optimum results; in fact a perfect arc can be achieved when all the parameters are in conformity. Parameters like welding current, arc voltage and gas flow ratewill affect the weld characteristics to a great extent. Because these factors can be varied over a large range, they are considered the primary adjustments in any welding operation. Their values should be recorded for every different type of weld to permit reproducibility.

1.1 GMAW can be done in three different ways:

Semiautomatic Welding - equipment controls only theelectrode wire feeding. Movement of welding gun is controlled by hand. This may be called hand-held welding.
Machine Welding - uses a gun that is connected to amanipulator of some kind (not hand-held). An operator has to constantly set and adjust controls that move the manipulator.
Automatic Welding - uses equipment which welds without the constant adjusting of controls by a welder oroperator.On some equipment, automatic sensing devices control the correct gun alignment in a weld joint.

1.2Working Principle ofMig Welding:

As shown in fig. the electrode in this process is in the form of wire and continuously fed towards the work during the process. At the same time inert gas (e.g. argon, helium, or) is passed around electrode from the same torch. Inertgas usually argon, helium, or a suitable mixture of these is used to prevent the atmosphere from contacting the molten metal and HAZ (Heat Affected Zone). When gas is supplied, it gets ionized and an arc is initiated in between electrode and work piece. Heat is therefore produced. Electrode melts due to the heat and molten filler metal falls on the heated joint.

The arc may be produced between a continuously fed wire and the work. Continuous welding with coiled wire helps high metal depositions rate and high welding speed. The filler wire is generally connected to the positive polarity of DC source forming one of the electrodes. The workpiece is connected to the negative polarity. The power source could be constant voltage DC power source, with electrode positive and it yields a stable arc and smooth metal transfer with least spatter for the entire current range.The gas shield around it does not ionized, which prevents weld against atmospheric co contamination and surface oxidation. Some torch has water cooling systems. MIG welding is also called Gas Metal Arc Welding. The filler metal is transmitted from electrode to joint by different methods. It is dependent on the current passing through the electrode and voltage.

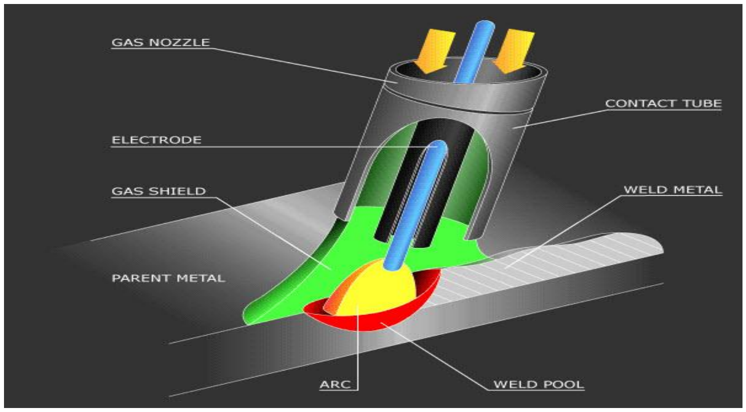

Figure 1: Working principles of GMAW

1.3GMAW / MIG welding applications:

MIG may be operated in semiautomatic, machine, or automatic modes. All commercially important applicable metals such as carbon steel, high-strength, low-alloy steel, and stainless steel, aluminum, copper, titanium, and nickel alloys can be welded in all positions with this process by choosing the appropriate shielding gas, electrode, and welding variables.

1.4MIG weldingeffectingparameters:

Weld quality and weld deposition rate both are influenced very much by the various welding parameters and joint geometry. Essentially a welded joint can be produced by various combinations of welding parameters as well as joint geometries. These parameters are the process variables which control the weld deposition rate and weld quality. The weld bead geometry, depth of penetration and overall weld quality depends on the following operating variables.

- Electrode size, Welding current, Arc voltage
- Arc travel speed, Welding position
- Gas Flow rate, Shielding Gas composition
- Electrode extension (length of stick out)
- Wire Feed Rate

II. LITERATURE REVIEW

G.Haragopal, P V R Ravindra Reddy and J V Subrahmanyam presented a method to design process parameters that optimize the mechanical properties of weld specimen for aluminium alloy (Al -65032), used for construction of aerospace wings. The process parameters considered for the study were gas pressure, current, groove angle and pre-heat temperature. Process parameters were assigned for each experiment. The experiments were conducted using the L9 orthogonal array. Optimal process parameter combination was obtained. Along with this, identification of the parameters which were influencing the most was also done. This was accomplished using the S/N analysis, mean response analysis and ANOVA. Mechanical properties obtained for three samples of each run were obtained. Signal to noise ratio for each quality (S/N) ratio for each quality characteristic was calculated, significant parameters were identified and optimum input parameter for each quality characteristic were predicted from S/N values and mean response. Analysis of variance (ANOVA) ascertained significant parameters identified through S/N analysis. A confirmation test was conducted at optimum conditions to ensure correctness of analysis **[1].**

Omar Bataineh, Omar Barqawi was identified and optimized the main factors that have significant effect on weld joint strength through factorial design experiments. Welding experiments were carried out using MIG Welding process and An ER1100 filler wire with 1.2 *mm* in diameter was used as a consumable electrode. The shielding gas used was 100% pure

Argon. Test specimens were composed of two pieces each, and each piece was 100 *mm* × 50 *mm* × 8 *mm* in size and made of 1070 aluminum alloy.

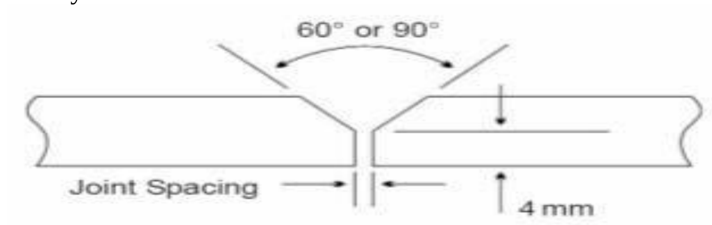

Figure 2: Joint geometry for the welding specimens

The factors that were studied are arc voltage, filler feed rate, gas flow rate, specimen edge angle and preheat temperature. Results of factorial design experiments and the analysis of variance (ANOVA) showed that arc voltage and filler feed rate are the only significant factors of the five. Optimal settings of arc voltage and filler feed rate were reached using regression analysis at 24 V and 7 in/s, respectively, at which the mean weld strength is maximum **[2].**

IzzatulAini Ibrahim, Syarulashrafmohamat, Amalina.amir,et. al performed experiments in the effects of different parameters on welding penetration, micro structural and hardness measurement was measured in mild steel that having the 6mm thickness of the base metal by using the robotic gas metal arc welding. The variable parameters are arc voltage, welding current and welding speed. The penetration, microstructure and hardness were measured for each specimen after the welding process and the effect it was studied. As a result, it obvious that increasing the parameter value of welding current increased the value of depth of penetration. Other than that, arc voltage and welding speed is another factor that influenced the value of 2 depth of penetration. In these experiments use 100 % shielding gas and wire electrode is ER70S 6 with 1.2 diameter nozzle to work distance is 12mm and only one pass on weld plate. In Figure ,The effect of welding current on penetration was present in welding speed as constant as 20 cm/min and the value of penetration was increased by increasing the value of welding current 90, 150 and 210 A. The highest penetration is 2.98 mm at 22 V and 210 A. Welding speed as constant as 40 cm/min and the value of penetration was increased by increasing the value of welding current 90, 150 and 210 A. The highest penetration is 3.26 mm at 22 V and 210 A. The change in the value depth of penetration is similar at voltage of 26V and 30V. The welding speed as constant as 60 cm/min and the value of penetration was increased by increasing the value of welding current 90, 150 and 210 A. The highest penetration is 2.79 mm at 26 V and 210 A **[3].**

A. S. Vagh and S. N. Pandya studied the effect of Friction Stir Welding process parameters on the mechanical properties of the AA 2014-T6 alloy joints produced by friction stir welding have been discussed. Effects of tool design, tool rotation speed & tool travels speed on mechanical properties have been analyzed using Taguchi orthogonal array design of experiments technique. The study indicates that Tool design is the main process parameter that has the highest statistical influence on mechanical properties. However, other parameters such as Tool rotation speed & Tool travel speed has also significant effect on mechanical properties **[4].**

S.C. Juang and Y.S. Tarng use Taguchi method to analyze the weld pool geometry in the Tungsten inert gas (TIG) welding of stainless steel. The input parameters were selected are front height, back height, front width, and back width. The modified Taguchi method is adopted to solve the optimal weld poolgeometry with four smaller-the-better quality characteristics. Experimental results have shown that the quality characteristics i.e. front height; front width, back height and back width of the weld pool in the TIG welding of stainless steel are greatly improved by using this approach **[5].**

III. SELECTION OF MATERIAL

Austenitic is the most widely used type of stainlesssteel. It has a nickel content of at least of 7%, which makes the steel structure fully austenitic and gives it ductility, a large scale of service temperature, non-magnetic properties andgood weld ability. 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 advisable 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 iron-chromium-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 machinability 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:

- Stainless steels work-harden considerably
- Stainless steels have low thermal conductivity Stainless steels have high toughness
- Stainless steels tend to be sticky
- Stainless steels have poor chip-breaking characteristics

Table 1: Chemical Composition For 304

C Composition:	**Type 304 %**
Carbon	0.08 max.
Manganese	2.00 max.
Phosphorus	0.045 max.
Sulfur	0.030 max.
Silicon	0.75 max.
Chromium	18.00-20.00
Nickel	8.00-10.05
Nitrogen	0.10 max.

As the stainless steel is classified in different categories like austenitic, ferritic, martensitic etc., from this we have chosen austenitic stainless steel (304) because of its low cost, easy availability in the market and wide application.

IV. TAGUCHI METHOD

Taguchi design of experiment is one of these techniques which are used widely. The Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. The Taguchi method was developed by Dr. Genichi Taguchi of Japan who maintained that variation. Taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning.The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varies.

An orthogonal array is a method of designing experiment that usually requires only a fraction of the full factorial combinations. An orthogonal array means the design is balanced so that factor levels are weighted equally. Because of this, each factor can be evaluated independently of all the other factors, so the effect of one factor does not influence the estimation of another factor.

Table 2: An L-9 Orthogonal Array Is Shown Below

Sr. No.	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Signal to Noise Ratio

The signal tonoise (S/N) ratios has obtained usingTaguchi's methodology. The 'signal' is the desirable value (mean) and the 'noise' is the undesirable value(standard deviation). Thus the S/N ratio represents the amount of variation present in the performancecharacteristic. Depending upon the objective of the performance characteristic, there can be various types of S/N ratios. There are 3 Signal-to-Noise ratios of common interest for optimization.

V. METHODOLOGY

The following are the steps which were followed to achieve the objective:

1) Selection of process parameters & their levels
2) Selection of quality characteristics
3) Selection of Orthogonal Array
4) Selection of Parent Metal & Filler Material
5) Preparation of steel plate specimen
6) After performing GMAW operation, the specimens were cut from the welded plate to carry out various tests.

The test carried out to achieve the objective:

- Rockwell Hardness Test

VI. EXPERIMENTATION

The experiments have been conducted using an Auto K 400 Power Source and amanual Welding Set up. In this welding machine automatic feeler wire feeding units are provided. For experimentation, different parameters are set up.

6.1 Experimental parameters:

Input parameters:

1. Welding Current
2. Welding Voltage

3. Gas Flow rate

Output parameters:

1. Hardness (Of Heat affected zone and Weld bead).

Table 3: Welding Parameters and Their Levels

Parameters	Unit	Level 1	Level 2	Level 3
Current	Ampere	150	200	250
Voltage	Volt	15	20	25
Gas Flow Rate	Kg/hr	10	20	30

Table 4: L-9 Orthogonal Array after Assignment of Parameters

Exp. No.	Current (Amp)	Voltage (Volt)	Gas Flow (Kg/hr)
1.	150	15	10
2.	150	20	20
3.	150	25	30
4.	200	15	20
5.	200	20	30
6.	200	25	10
7.	250	15	30
8.	250	20	10
9.	250	25	20

Welding specimen has been prepared to fabricate MIG welded jointsASS 304 specimen in the dimension 110mm x 40mm x 3mm was considered for welding with different parameters. Welding process has been carried out on MIG welding machine. Experiments were conducted based onTaguchi Method.

VII. RESULT & DISCUSSION

The aim of the experimental plan is to find the effect of parameters those are influencing the Hardness of Weld Bead& Heat Affected Zone of weldment. The experiments were developed based on an orthogonal array, with the aim of relating the influence of Welding Current, Arc Voltage and Gas Flow Rate. These design parameters are distinct and intrinsic feature of the process that influence and determine the composite performance.

7.1 Results of Statistical Analysis of Experiments

The results for various combinations of parameters were obtained by conducting the experiment as per the orthogonal array. The measured results were analyzed using the commercial software MINITAB 15 specially used for the design of experiment applications. To measure the quality characteristics, the experimental values are transformed into signal to noise ratio. The influence of control parameters such as Arc Current, Arc Voltage & Gas Flow Rate on Hardness of weld zone & heat affected zone has been analyzed using Response table for signal to noise ratio.
The response tables show the average of each response characteristic (S/N ratios) for each level of each factor. The tables include ranks based on Delta statistics, which compare the relative magnitude of effects.
The Delta statistic is the highest minus the lowest average for each factor. Minitab assigns ranks based on Delta values; rank 1 to the highest Delta value, rank 2 to the second highest, and so on. Use the level averages in the response tables to determine which level of each factor provides the best result.

7.2 Taguchi Analysis for Hardness (Weld Bead & Heat Affected Zone)

TABLE 5: Results of L9 orthogonal array for Hardness

CURRENT	VOLTAGE	GAS FLOW RATE	HARDNESS AT HAZ	HARDNESS ON WELD BEAD	S/N RATIO
150	15	10	85.5	82.5	31.9535
150	20	20	85.5	83.5	35.5268
150	25	30	86.5	80.5	25.8810
200	15	20	84.5	81.5	31.8494
200	20	30	84.5	81.5	31.8494
200	25	10	86.5	82.0	28.4574
250	15	30	85.5	83.5	35.5268
250	20	10	84.5	85.5	41.5987
250	25	20	85.5	81.5	29.4028

7.2.1 Response Table for Signal to Noise Ratio (Hardness)

Nominal is best (L 10*Log (Y bar**L 2/s**L 2))

TABLE 6: Response Table for S/N Ratio (Hardness)

Level	Arc Current	Arc Voltage	Gas Flow Rate
1	31.12	33.11	**34.00**
2	30.72	**36.32**	32.26
3	**35.51**	27.91	31.09
Delta	4.79	8.41	2.92
Rank	**2**	**1**	**3**

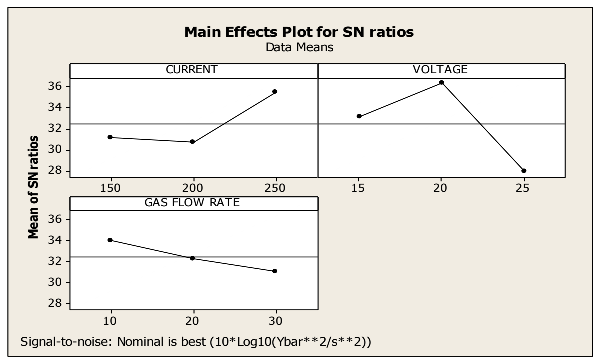

Figure3: Main effect plot for S/N Ratio (Hardness)

In our experimental analysis for hardness of weld zone and heat affected zone, the ranks indicate that Arc Voltage has the greatest influence on the S/N ratio and on the mean having highest rank 1. For S/N ratio, arc current has the next greatest influence, followed by gas flow rate. Here, because our goal is to increase the weld ability by keeping the hardness at nominal value, we want factor levels that produce the highest mean. In Taguchi experiments, we always want to maximize the S/N ratio. The level averages in the response tables show that the S/N ratios and Mean is maximized when the value of Arc Current was 250A, the Arc Voltage was 15 V and the gas flow rate was 10 kg/hr.

7.2.2 Analysis Of Variance for S/N Ratios (Hardness)

TABLE 7: Analysis of Variance Table for Signal to Noise Ratio of Hardness

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Arc Current	2	42.375	42.375	21.188	4.93	0.169	25
Arc Voltage	2	108.085	108.085	54.043	12.59	0.074	63

Gas Flow Rate	2	12.929	12.929	6.465	1.51	0.399	7
Residual Error	2	8.587	8.587	4.294			5
Total	8	171.977					

Table 7 shows the result of the analysis of variance (ANOVA) for the Hardness (WB& HAZ). The analysis of variance was carried out at 95% confidence level. The main purpose of analysis of variance is to investigate the influence of the design parameters on Hardness by indicating that which parameters is significantly affected the quality characteristics. In our experimentation work, we have generated results for S/N ratios of Hardness (WB&HAZ). The purpose of ANOVA is to investigate which welding process parameters significantly affect the quality characteristics. This is accomplished by separating the total variability of the S/N Ratios, which is measured by the sum of squared deviations from the total mean of the S/N ratio, into contributions by each welding process parameter and the error. The percentage contribution by each of the welding process parameters in the total sum of the squared deviations can be used to evaluate the importance of the process parameter change on the quality characteristic. From fig 3 we can conclude that Arc Voltage is significantly affects the Hardness of Weld Bead& Heat Affected Zone with contribution of 63% followed by ArcCurrent with contribution of 25% and Gas Flow Rate with contribution of 7%.

The purpose of ANOVA is to investigate which welding process parameters significantly affect the quality characteristics. This is accomplished by separating the total variability of the S/N Ratios, which is measured by the sum of squared deviations from the total mean of the S/N ratio, into contributions by each welding process parameter and the error. The percentage contribution by each of the welding process parameters in the total sum of the squared deviations can be used to evaluate the importance of the process parameter change on the quality characteristic.

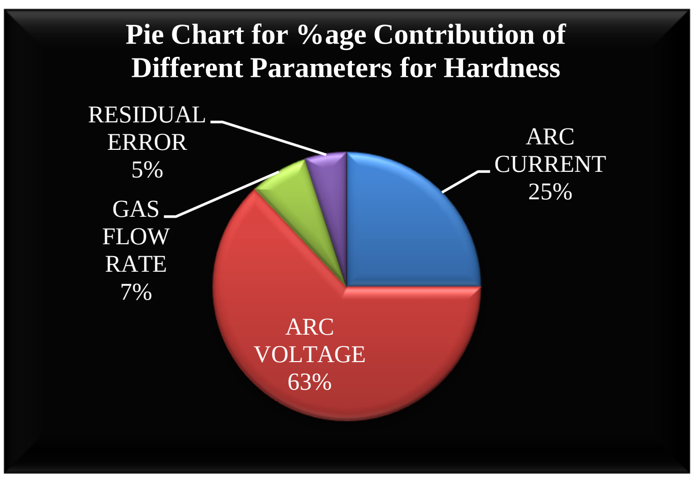

Figure 4: *Pie Chart for %age Contribution of Different Parameters for Hardness*

From fig 4 we can conclude that Arc Voltage is significantly affects the Hardness of Weld Bead& Heat Affected Zone with contribution of 63% followed by ArcCurrent with contribution of 25% and Gas Flow Rate with contribution of 7%.

VIII. CONCLUSION

The present study can be concluded in the following steps:
1. Taguchi design of experiment technique can be very efficiently used in the optimization of welding parameters in manufacturing operations.
2. Arc Voltage is significantly affects the Hardness of Weld Bead& Heat Affected Zone with contribution of 63% followed by Arc Current with contribution of 25% and Gas Flow Rate with contribution of 7%.

3. Thus design of experiments by Taguchi method was successfully used to find the optimum welding parameters for Hardness of Austenitic Stainless Steel (AISI 304).

IX. SCOPE FOR FUTURE WORK

This study presented an efficient method for determining the optimal Gas Metal Arc welding parameters for increasing weldability of Austenitic Stainless Steel (AISI 304)under varying conditions through the use of the Taguchi parameter design process. This process was applied using a specific set of control and a response variable of Hardness of Weld Bead& Heat Affected Zone. The use of the L9 (3 3) orthogonal array, with Three control parameters (Arc Current, Arc voltage & Gas Flow rate) used for this study to be conducted with a sample of 9 work pieces.
It is also carried out for other stainless steel material with more control factors and compared with AISI stainless steels to recommend which material is suitable process for recommending the process at a minimum cost and maximum profit for the organization and to minimize the weld defects as well as welding problems for further future work.

REFERENCES

[1]. Rajiv Suman and Dr. Jatindar Kumar, "Assessment of Deposition Rate in MIG Welding of Stainless Steel "*International Journal of Research in Advent Technology*, Vol.2, No.3, E-ISSN: 2321-9637, March 2014.
[2]. S. Naveenkumar, Dr. K. SooryaPrakash, G. Gokilakrishnan, N. V. Kamalesh, "Parametric Optimization Of Welding Process Of Low Carbon Steel (Aisi 1019) By Using Taguchi's Approach"*International Journal For Technological Research In Engineering*, Volume 1, ISSN (Online): 2347 – 4718, Issue 7, March-2014.
[3]. Dinesh Mohan Arya, VedanshChaturvedi, JyotiVimal "Parametric Optimization Of Mig Process Parameters Using Taguchi And Grey Taguchi Analysis" *International Journal of Research in Engineering & Applied Sciences* ISSN: 2249-3905.
[4]. Pawan Kumar, Dr. B.K.Roy, NishantVerma "Parameters Optimization for Gas Metal Arc Welding of Austenitic Stainless Steel (AISI 304) & Low Carbon Steel using Taguchi's Technique" *International Journal of Engineering and Management Research*, Vol.-3 ISSN No.: 2250-0758, Issue-4, August 2013.

[5]. G. Haragopal, P V R Ravindra Reddy, G Chandra Mohan Reddy, J V Subrahmanyam, " Parametric design for MIG welding of Al- 65032 alloy using Tagauchi Method ", *Journal of Scientific and Industrial Research*, Vol. 70, pp.844 - 850, October 2011.
[6]. M. Aagakhani, E. Mehardad, E. Hayati, "Parameteric optimization of GMAW process by Tagauchi Method on weld dilution. ", *International Journal of Modeling and Optimization*, Vol. 1, No. 3, August'2011.
[7]. Ashok Kr. Mishra, RakeshSheokand, Dr. R K Srivastava, "TribologicalBehaviour of Al-6061 / SiC Metal Matrix Composite by Taguchi's Techniques", *International Journal of Scientific and Research Publications*, Volume 2, Issue 10, October 2012 1 ISSN 2250-3153.
[8]. Sandip Bhattacharya, Kamal Pal, Surjya K. Pal, "Multi-sensor Based prediction of metal deposition in pulsed GMAW using various soft computing models ", *ELSEVIER* , Applied Soft Computing 12 (2012) 498–505, August' 2011.
[9]. Abbasi.K, Alam.S, Khan.M.I, "An experimental study on effect of increased pressure on MIG welding arc ", *International Journal of Applied Engineering Research*, DINDIGUL, Vol.2,No. 1, 2011.
[10]. Mr. L Suresh Kumar, Dr. S M Verma, P kiran Kumar, Dr. T Shiva Shanker, "Experimental Investigation for welding aspects of AISI 304 & 316 by Tagauchi Technique for process of TIG & MIG welding ", *International Journal of Engineering Trends and Technology*, Vol.2, Issue2, 2011.
[11]. Satoshi Yamane, Takuya Yamazaki, TomoakiKaneta, Toru Nakazima, "Experimental and numerical simulation in temperature distribution and weld distortion in GMA welding ", *Journal of Japan welding society,* Vol. 29 2011,.
[12]. Sanjay Kumar, P. SrinivasaRao, A Ramakrishna, "Effect of eccentricity and arc rotational speed on weld bead geometry in pulsed GMAW of 5083 Al Alloy *", Journal of Mechanical Engineering Research*, Vol. 3. (6), pp. 186-196, June 2011.
[13]. M.P.Garg, Sarbjit Singh, Jodh Singh, "Experimental investigation of mechanical properties of MIG weldments of Al Alloy plates ", *Journal of Engineering and Technology,* Jul – Dec'2011, Vol. 1, Issue 2.
[14]. Lenin.N, Shiva kumar M.,Vigneshkumar D, "Process parameter optimization in arc welding of dissimiliar metals ", *ThammasatInt .J. Sc. Tech*, Vol. 15,No. 3, Sept'2010.
[15]. K. Kishore, P.V.Gopal Krishna, K. Veladri, SayedQasim Ali, "Analysis of defects gas shielded arc welding of AISI 1040 steel using Tagauchi method ", *ARPN Journal of Engineering and Applied Science*, VOL. 5, NO. 1, JANUARY 2010.

[16]. FarhadKohalan, Mehdi Heidari, "A New approach for predicting and optimizing weld bead geometry in GMAW ", *International Journal of Mechanical System Science and Engineering*, 2,2010.

[17]. Emilie Le Guen, Muriel Carin, RemiFabbro, "3D heat transfer model of hybrid laser welding of S355 steel and experimental validation *", International Journal of Heat and Mass transfer*, 54 (2011) 1313–1322, Dec'2010.

[18]. Her-Yueh Huang, "Effect of activating flux on welding characteristics in GMAW", *ELSEVIER*, 31 (2010) 2488–2495, Nov'2009.

[19]. Sukhomay Pal, Santosh K. Malviya, Surja K. Pal, "Optimization of quality characteristics parameter in pulsed GMAW process using Grey-Based Tagauchi Method ", *International Journal of Advanced Manufacturing Technology*, (2009) 44:1250–1260, Jan'2009.

[20]. BappaAcherjee, SourenMitra, Arunanshu S. Kuar, Dipten Mishra, "Use of Tagauchi Quality loss function to optimize quality characteristics using laser transmission welding process of thermoplastics", *ASME Early Career Technical Journal*, ASME 2009.

[21]. K.Y. Benyounis, A.G. Olabi, "Optimization of different welding process using statistical and numerical approaches-A reference guide", *ELSEVIER, Advances in Engineering Software* 39 (2008) 483–496, Mar'2007.

[22]. J.P.Ganjigatti, D.K.Pratihar,A.RoyChoudhury, "Modeling of MIG welding process using statistical approaches ", *International Journal of Advanced Manufacturing Technology*, (2008) 35:1166–1190, Nov'2006.

[23]. J.P. Ganjigatti, Dilip Kumar Pratihar, A.RoyChoudhury, "Global verses Cluster Wise Regression Analysis for prediction of bead geometry in MIG welding process", *ELSEVIER*, Dec'2006.

