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Taguchi Optimization of TIG Welding for Maximizing Weld Strength of Aluminium 8011

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ABSTRACT: Tungsten Inert Gas (TIG) welding is one of the most widely used processes in industry. The welding parameters are the most important factors affecting the cost and quality of welding. This paper pertains to the improvement of ultimate tensile strength of Aluminium 8011 weld specimen made of tungsten inert gas welding. A plan of experiments based on Taguchi method has been used. L_{16} orthogonal array has been used to conduct the experiments at different levels of welding parameters like pulse current, peak current, pulse frequency and pulse duty cycle. Signal-to-noise ratio (S/N ratio), analysis of variance (ANOVA) and graphical mean effect plots for S/N ratio are employed to investigate the optimal level of process parameters and influence of welding parameters on weld strength. Finally the confirmatory test has been carried out at optimal operating level to compare the predicated value of ultimate tensile strength with the experimental value.

KEYWORDS: TIG welding, Optimization, DOE, Taguchi method, Orthogonal array, S/N ratio, ANOVA.

I. INTRODUCTION

Tungsten Inert Gas (TIG) welding is an important process in many industrial operations for different types of materials like aluminum, mild steel and stainless steel alloy grades. TIG welding is an arc welding process that produces coalescence of metals by heating them with an arc between a non-consumable electrode and the base metal. TIG welding offers several advantages such as joining of dissimilar metals, low heat affected zone, absence of slag etc. The input parameters play a very significant role in determining the quality of a welded joint. The optimization of TIG welding process parameters play important role for the final product quality in terms of mechanical properties and joint efficiency. Therefore, welding parameters that affecting the arc 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.

In order to overcome this problem in welding, various optimization methods are available to define the desired output variables through developing mathematical models to specify the relationship between the input parameters and output variables. Design of experiment (DOE) technique has been applied to carry out such optimization. DOE is a statistical technique that runs minimum number of experiments to optimize process. Design of Experiments is an experimental or analytical method that is commonly used to statistically signify the relationship between input parameters to output responses, where by a systematic way of planning of experiments, collection and analysis of data is executed. DOE has wide applications especially in the field of science and engineering for the purpose of process optimization and development, process management and validation tests. Major approaches in Design of Experiments are: factorial design, Taguchi method and response surface methodology. Taguchi method has been adapted for many applications in different areas.

Pasupathy et al. [1] investigated the optimal process parameters of Tungsten inert gas welding for improving weld strength of low carbon steel – aluminium alloy 1050 weld specimen using Taguchi method. Sapakal et al. [2] applied Taguchi method for optimization of process parameters of metal inert gas welding for maximizing the weld penetration depth of mild steel C20 material. Manihar Singh et al. [3] analyzed the optimal parametric combinations of submerged

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

arc welding process for maximization of weld bead geometry of mild steel plates using Taguchi method. Nirmalendhu Choudhury et al. [4] employed Taguchi method to find optimal parametric combinations in Tungsten inert gas welding for improvement of ultimate load of stainless steel – mild steel welded joints. Avinash Pachal et al. [5] carried out a review on Taguchi optimization of process parameters in friction welding of 6061 Aluminium alloy and 304 steel for maximization of tensile strength. Ajit Khatter et al. [6] developed Taguchi model to find the optimal parametric conditions in tungsten inert gas welding for improving tensile strength of stainless steel 304 weld specimen. Akella et al. [7] applied Taguchi method for distortion control in tungsten inert gas welding. Patil et al. [8] used Taguchi method for optimization of metal inert gas welding for maximizing weld strength of AISI 1030 welded joints. The present study focuses on Taguchi method on design of experiments to build the mathematical model for prediction of optimal parameter setting for high weld strength.

II. TAGUCHI METHOD

Genichi Taguchi, a Japanese scientist, developed a technique based on orthogonal array of experiments. Taguchi method has become a powerful tool for improving productivity during research and development, so that high quality products can be produced quickly. The quality engineering method of Taguchi, employing design of experiment (DOE), is one of the most important statistical tools for designing the high quality systems at reduced cost. Taguchi methods provide an efficient and systematic way to optimized designs for performance, quality and cost. Taguchi methods have been widely utilized in engineering analysis and consist of a plan of experiments with the objective of acquiring data in a controlled way, in order to obtain information about the behavior of a given process. Optimization of process parameters is the key step in the Taguchi's method to achieve high quality without increasing cost. This is because, optimization of process parameters can be improve quality characteristic and optimal process parameters obtained from Taguchi method are insensitive to the variation of environment conditions and other noise factors.

Classical process parameter design is complex and not an easy task. A large number of experiments have to be carried out when the number of the process parameters increases. To solve this task, the Taguchi method uses a special design of orthogonal arrays to study the entire process parameter space with a small number of experiments only. Using an orthogonal array to design the experiment could help the designers to study the influence of multiple controllable factors on the average of quality characteristics and the variations in a fast and economic way, while using a signal-to-noise ratio to analyze the experimental data could help the designers of the product or the manufacturer to easily find out the optimal parametric combinations.

An advantage of the Taguchi method is that it emphasizes a mean performance characteristic value close to the target value rather than a value within certain specification limits, thus improving the product quality. The greatest advantage of this method is the saving of effort in conducting experiments; saving experimental time, reducing the cost, and discovering significant factors quickly.

A loss function is then defined to calculate the deviation between the experimental value and the desired value. Taguchi recommends the use of the loss function to measure the deviation of the quality characteristic from the desired value. The value of the overall loss function is further transformed into a signal-to-noise (S/N) ratio. Usually, there are three categories of the quality characteristic in the analysis of the S/N ratio, *i.e.* the lower-the-better, the larger-the-better, and the nominal-the-better. Therefore, for obtaining more weld strength, the optimal level of the process parameters is the level with the highest S/N ratio. Furthermore, a statistical analysis of variance (ANOVA) is performed to see which process parameters are statistically significant. The optimal combination of the process parameters can then be predicted. Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the process parameter design.

Taguchi proposed that engineering optimization of a process or product should be carried out in a three-step approach: System design, Parameter design and Tolerance design. System design is the conceptualization and synthesis of a product or process to be used. The system design stage is where new ideas, concepts and knowledge in the areas of science and technology are utilized by the design team to determine the right combination of materials, parts, processes and design factors that will satisfy functional and economical specifications. Parameter design is related to finding the appropriate design factor levels to make the system less sensitive to variations in uncontrollable noise factors, *i.e.*, to

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

make the system robust. Tolerance design occurs when the tolerances for the products or process are established to minimize the sum of the manufacturing and lifetime costs of the product or process. In the tolerance design stage, tolerances of factors that have the largest influence on variation are adjusted only if after the parameter design stage, the target values of quality have not yet been achieved. The steps followed in Taguchi optimization are as follows:

1. Select control and noise factors
2. Select levels for each factor
3. Select Taguchi orthogonal array
4. Conduct the experiments
5. Measure the response factor
6. Calculate Signal-to-noise ratio
7. Calculate mean S/N ratio and plot mean S/N ratio graph
8. Predict optimal process parameter level
9. Formulate ANOVA table
10. Run confirmation experiment

III. EXPERIMENTAL PROCEDURE

The work material used for present work is Aluminium 8011. The dimensions of the work piece are: length 100 mm, width 25 mm and thickness 6 mm. For selection of workpiece and dimensions, reference of the procedure handbook of Arc Welding & Welding Process Technology by P. T. Houldcroft is referred. The setup has been made ready and prepared for doing TIG welding. Now weld joints are made under varied conditions of welding as given by orthogonal array of Taguchi method. The selected welding parameters and levels for each factor are given in Table 1.

Table 1: Welding parameters and their levels

Symbol	Parameters	Level 1	Level 2	Level 3	Level 4
A	Pulse current (A)	150	165	180	210
B	Pulse duty cycle (%)	30	45	60	90
C	Base current (A)	75	90	105	135
D	Pulse frequency (Hz)	50	150	-	-

Orthogonal arrays are the standard arrays which are selected based on number of parameters selected and levels of parameters. L_{16} orthogonal array is chosen from Minitab 16 software as shown in Table 2. Tensile tests are conducted in Universal Testing Machine (UTM) as shown in Fig. 1. In universal testing machine, welded workpiece is kept fixed at one end and stretched on the other end. At the point of ultimate tensile strength, weld gets broken.

Table 2: L_{16} Orthogonal array

Experiment number	Pulse Current	Pulse Duty Cycle	Base Current	Pulse Frequency
1	1	1	1	1
2	1	2	2	1
3	1	3	3	2
4	1	4	4	2
5	2	1	2	2
6	2	2	1	2
7	2	3	4	1

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

8	2	4	3	1
9	3	1	3	1
10	3	2	4	1
11	3	3	1	2
12	3	4	2	2
13	4	1	4	2
14	4	2	3	2
15	4	3	2	1
16	4	4	1	1



Fig. 1. Tensile testing in UTM

IV. ANALYSIS OF S/N RATIO

Taguchi has created a transformation of repetition data to another value, which is a measure of the variation present. The transformation is known as signal-to-noise (S/N) ratio. In Taguchi Method, the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value (standard Deviation) for the output characteristic. Therefore, S/N ratio is the ratio of mean to the standard deviation. S/N ratio used to measure the quality characteristic deviating from the desired value. S/N ratio is log function of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results. The S/N ratio S is defined as

$$S/N = - 10 \log_{10} (M.S.D)$$

where, M.S.D. is the mean square deviation for the output characteristic. According to Quality Engineering, the characteristic that higher observed value represents better performance, as in case of tensile strength, is known as "larger is better". In this research, for welded joints, higher value of ultimate tensile strength is preferred so only weld can withstand more load. Therefore, for ultimate tensile strength "larger is better" is selected for obtaining optimum machining performance characteristics. Using Minitab 16 software, S/N ratio is calculated as shown in Table 3.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

Table 3: Experimental result for UTS and S/N ratio

Experiment Number	Pulse Current (A)	Pulse Duty Cycle (%)	Base Current (A)	Pulse Frequency (Hz)	Tensile Strength (N/mm ²)	S/N Ratio
1	1	1	1	1	73.248	37.2959
2	1	2	2	1	68.016	36.6522
3	1	3	3	2	78.480	37.8952
4	1	4	4	2	99.408	39.9484
5	2	1	2	2	120.336	41.6079
6	2	2	1	2	130.800	42.3322
7	2	3	4	1	115.104	41.2218
8	2	4	3	1	115.104	41.2218
9	3	1	3	1	130.800	42.3322
10	3	2	4	1	141.264	43.0006
11	3	3	1	2	141.264	43.0006
12	3	4	2	2	115.104	41.2218
13	4	1	4	2	136.030	42.6727
14	4	2	3	2	115.104	41.2218
15	4	3	2	1	125.560	41.9770
16	4	4	1	1	130.030	42.2809

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 greatest mean S/N ratio. Mean S/N ratio for welding parameters at different levels is calculated as shown in Table 4.

Table 4: Mean S/N ratio for different levels

Levels	Pulse Current (A)	Pulse Duty Cycle (%)	Base Current (A)	Pulse Frequency (Hz)
1	37.95	40.98	41.23	40.75
2	41.60	40.80	40.36	41.24
3	42.39	41.02	40.67	-
4	42.04	41.17	41.71	-

Using calculated mean S/N ratio for different levels, mean S/N ratio graph is plotted as shown in Fig. 2. From graph, we can find the optimal process parameter level resulting more ultimate tensile strength. Table 5 shows the optimal operating level of process parameters.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

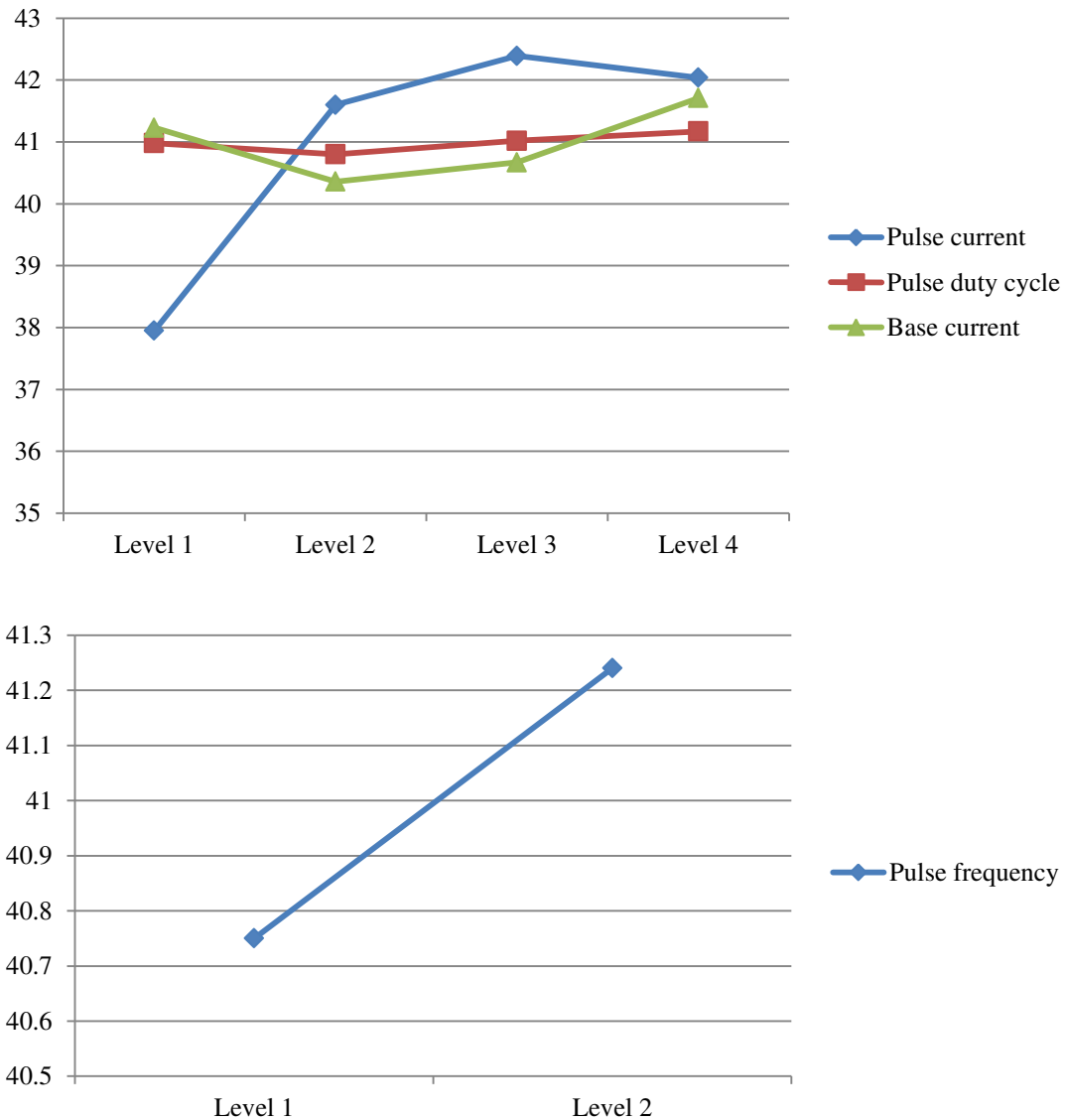


Fig. 2. Mean S/N ratio graph

Table 5: Optimal operating level

Parameters	Optimal operating level	Operating value
Peak Current	Level 3	180 A
Pulse duty cycle	Level 4	90 %
Base Current	Level 4	135 A
Pulse frequency	Level 2	150

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

ANALYSIS OF VARIANCE (ANOVA)

ANOVA is a collection of statistical models used to analyze the difference between group means and their associated procedures (such as "variation" among and between groups), developed by R.A. Fisher. ANOVA is the statistical method used to interpret experimental data to make the necessary decisions. A better feel for the relative effect of the different welding parameters on the ultimate tensile strength was obtained by decomposition of variance, which is called analysis of variance. ANOVA helps in formally testing the significance of all main factors and their interactions by comparing the mean square against an estimate of experimental errors at specific confidence levels. Through ANOVA, the parameters can be categorized into significant and insignificant process parameters. A statistical analysis of variance is performed to see which process parameters are statistically significant at 95% confidence level. In addition to the S/N ratio, analysis of variance can be employed to indicate the impact of process parameters on mechanical properties of weld joints. The purpose of ANOVA experimentation is to reduce and control the variation of a process. Subsequently, decisions can be made concerning which parameters affect the performance of the process. The purpose of the analysis of variance (ANOVA) is to investigate which design parameters significantly affect the quality characteristic. This is accomplished by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean S/N ratio, into contributions by each of the design parameters and the error. First, the total sum of squared deviations SS_T from the total mean S/N ratio $\bar{\eta}_m$ can be calculated as,

$$SS_T = \sum_{j=1}^p (\eta_j - \bar{\eta}_m)^2$$

where p is the number of experiments in orthogonal array, $\bar{\eta}_m$ is total mean of signal to noise ratio, and η_j is the mean of signal to noise ratio for the jth experiment.

In the ANOVA test, F-tests value of the parameters are comparing with the standard F table value ($F_{0.05}$) at 5% significance level (95% confidence level). Statistically, F-test provides a decision at some confidence level as to whether these estimates are significantly different. Larger F-value indicates that the variation of the process parameter makes a big change on the performance. F ratio is a ratio of the mean square error to the residual error and is traditionally used to determine the significance of a factor. If P-values in the table are less than 0.05 then the corresponding variables considered as statistically significant. This means that if P value for all parameters is greater than 0.05 means none of these parameters do have significant effect on the response factor at 95% confidence level. The relative importance of the welding parameters with respect to the ultimate tensile strength was investigated to determine more accurately the optimum combinations of the welding parameters by using ANOVA.

Table 6: ANOVA table

Source	Sum of squares	Degree of freedom	Mean square	F value	P - value prob > F	Contribution %
A : Pulse current	50.71	3	16.90	18.14	0.0041	87.21
B : Pulse duty cycle	0.27	3	0.091	0.098	0.9578	0.47
C : Base current	4.28	3	1.43	1.53	0.3151	7.35
D : pulse frequency	0.96	1	0.96	1.03	0.3568	4.95
Error	4.66	5	0.93			
Total	60.88	15				

The parameter with larger F value indicates that the small variation of the process parameter will give more effect in response factor. From the result of ANOVA table, pulse current was found to be the major factor affecting ultimate

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

tensile strength since its F value is 18.14 and base current was found to be second ranking factor since its F value is 1.53. Pulse frequency ranks third since its F value is 1.03. Pulse duty cycle ranks last since its F value is 0.098. From ANOVA table, it is noted that P value of pulse current is 0.0041 which is less than 0.05. So it is clear that pulse current only has significant effect on ultimate tensile strength at 95% confidence level. Base current, pulse duty cycle and pulse frequency not have significant effect at 95% confidence level.

CONFIRMATORY TEST

Once the optimal level of design parameters has been selected, the final step is to predict and verify the improvement of the quality characteristic using the optimal level of design parameters. The estimated S/N ratio using the optimal level of the design parameters can be calculated as,

$$\hat{\eta} = \eta_m + \sum_{i=1}^n (\hat{\eta}_i - \eta_m)$$

where η_m is the total mean of S/N ratio, $\hat{\eta}_i$ is the mean S/N ratio at the optimum level, and the n is the number of welding parameter that significantly affect the performance. Confirmation experiment is done at optimal process level and actual ultimate tensile strength found to be 484 N/mm². The comparison of the predicted strength with actual strength using the optimal parameters is shown in Table 7. Good agreement between the predicted and actual penetration being observed.

Table 7: Result of conformation experiment

	Initial process parameters	Optimal process parameters		Improvement in S/N ratio
		Predicted	Actual	
Level	A ₃ B ₃ C ₁ D ₂	A ₃ B ₄ C ₄ D ₂	A ₃ B ₄ C ₄ D ₂	0.894
Tensile Strength (N/mm ²)	141.264	152.45	155.682	
S/N ratio	43.006	44.905	43.9004	

V. CONCLUSION

Taguchi optimization method was successfully applied to find the optimal level of TIG welding parameters for maximizing weld strength of Aluminium 8011 weld specimen. Taguchi orthogonal array, signal-to-noise ratio, analysis of variance and mean effects plots for S/N ratio were used for the optimization of welding parameters. The level of influence of the welding parameters on the weld strength is determined by using ANOVA. Confirmation experiment was also conducted and the effectiveness of Taguchi optimization method was verified. The experimental value of ultimate tensile strength that is observed from optimal level of welding parameters is 155.682 N/mm². The improvement in S/N ratio is 0.894.

REFERENCES

- [1] J. Pasupathy, V. Ravishankar, "Parametric Optimization of TIG Welding Parameters using Taguchi Method for Dissimilar Joint (Low carbon steel with AA1050)", International Journal of Scientific and Engineering Research, Vol. 4, Issue 11, 2013.
- [2] S. V. Sapakal, M. T. Telsang, "Parametric Optimization of MIG welding using Taguchi Design Method", International Journal of Advanced Engineering Research and Studies, Vol. 1, Issue 4, 2012.
- [3] L. Manihar Singh, Abhijit Saha, "Optimization of welding parameters for maximization of weld bead widths for submerged arc welding of mild steel plates", International Journal of Engineering Research & Technology, Vol. 1 Issue 4, 2012.
- [4] Nirmalendu Choudhury, Asish Bandyopadhyay and Ramesh Rudrapati, "Design optimization of Process Parameters for TIG Welding based on Taguchi Method", International Journal of Current Engineering and Technology, Issue 2, 2014.
- [5] Avinash S. Pachal, Amol bagesar, "Taguchi Optimization of Process Parameters in Friction Welding of 6061 Aluminum Alloy and 304 steel: A Review", International Journal of Emerging Technology and Advanced Engineering, Volume 3, Issue 4, 2013.
- [6] Ajit Khatter, Pawan Kumar, Manish Kumar, "Optimization of Process Parameters in TIG Welding using Taguchi of Stainless Steel -304", Vol. 4, Issue 1, 2014.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

- [7] S.Akella , B. Ramesh Kumar, “ Distortion Control in TIG Welding Process with Taguchi Approach”, Advanced Materials Manufacturing & Characterization Vol. 3, Issue 1, 2013
- [8] S. R. Patil, C. A. Waghmare, “Optimization of MIG Welding Parameters for Improving Strength of Welded Joints”, International Journal of Advanced Engineering Research and Studies, 2014
- [9] S. P. Kondapalli, S. R. Chalamalasetti and N. R. Damera, “Application of Taguchi based Design of Experiments to Fusion Arc Weld Processes: A Review”, International Journal of Technology and Management, Vol. 2, 2013.
- [10] Ugur Esme, “Application of Taguchi Method for the Optimization of Resistance Spot Welding Process”, The Arabian Journal for Science and Engineering, Volume 34, 2009.
- [11] C.A. Anoop, Pavan kumar, “Application of Taguchi Methods and ANOVA in GTAW Process Parameters Optimization for Aluminium Alloy 7039”, International Journal of Engineering and Innovative Technology, Vol. 2, Issue 11, 2013.
- [12] Pradeep Deshmukh, M. B. Sorte, “Optimization of Welding Parameters Using Taguchi Method for Submerged Arc Welding On Spiral Pipes”, International Journal of Recent Technology and Engineering, Vol. 2, Issue 5, 2013.
- [13] Norasiah Muhammad, Yupiter H.P Manurung, Mohammad Hafidzi, Sunhaji Kiyai Abas, Ghalib Tham and Esa Haruman, “Optimization and Modeling of Spot Welding Parameters with Simultaneous Multiple Response Consideration using Multi-objective Taguchi method and RSM”, Journal of Mechanical Science and Technology, 2012.
- [14] Mohan B. Raut, S. N. Shelke, “Optimization of Special Purpose Rotational MIG Welding by Experimental and Taguchi Technique”, International Journal of Innovative Technology and Exploring Engineering, Vol. 4, Issue 6, 2014.
- [15] Pawan Kumar, Dr.B.K.Roy, Nishant, “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, Issue 4, 2013.
- [16] Mohamadreza Nourani, Abbas S. Milani, Spiro Yannacopoulos, “Taguchi Optimization of Process Parameters in Friction Stir Welding of 6061 Aluminum Alloy: A Review and Case Study”, Scientific Research, 2010.
- [17] A. K. Pandey, M. I. Khan, K. M. Moeed, “Optimization of Resistance Spot Welding Parameters using Taguchi method”, International Journal of Engineering Science and Technology, Vol. 5, 2013.
- [18] Dr. D. R. Prajapati, Daman Vir Singh Cheema, “Optimization of Weld Crack Expansion defect of Wheel Rims by using Taguchi Approach: A case Study”, International Journal of Innovative Research in Science, Engineering and Technology, Vol. 2, Issue 8, 2013.
- [19] Sudesh Verma, Rajdeep Singh, “Optimization of Process Parameters of Metal Inert Gas Welding by Taguchi Method on CRC Steel IS 513 GR D”, International Journal of Advance Research In Science And Engineering, Vol. 3, Issue 9, 2014.
- [20] J. Pasupathy, V. Ravisankar, C. Senthilkumar, “Parametric Optimization of TIG welding of Galvanized Steel with AA1050 using Taguchi Method”, International Journal of Science and Research, Vol. 3, Issue 5, 2014.