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Multi Response Optimization of Pulsed Current Metal Inert Gas Welding Parameters for Ultimate Tensile Strength and Hardness of ASTM A106 Pipes Using Grey Relational Analysis

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Abstract - *Metal Inert Gas welding (MIG) process is an important welding operation for joining ferrous and non ferrous metals. The MIG input welding parameters are the most important factors affecting the quality of the welding and weld quality is strongly characterized by weld bead geometry. The optimization of parameters considering multiple performance characteristics of the Pulsed Current Metal Inert Gas Welding process for ASTM A106 Pipes using the GRA is presented. Performance characteristics including Ultimate Tensile Strength and Hardness were chosen to evaluate the welding effects. Those process parameters that are closely correlated with the selected performance characteristics in this study are the Current, Gas Flow Rate, and Wire Feed Rate. Experiments based on the appropriate L_{27} Orthogonal Array are conducted first. The normalized experimental results of the performance characteristics are then introduced to calculate the coefficient and grades according to Grey Relational Coefficient. Optimized process parameters simultaneously leading to higher Ultimate Tensile Strength and hardness was verified by a confirmation experiment.*

***Key Words*: Pulsed Current, ASTM A106 Pipes, Grey Relational Analysis, Ultimate Tensile Strength, Hardness.**

1. INTRODUCTION

Pulsed Current Metal Inert Gas Welding is widely used process, especially in pipe welding. It offers an improvement in quality and productivity over regular Gas Metal Arc Welding (GMAW). The process enables stable spray transfer with low mean current and low net heat input. It applies waveform control logic (Fig-1) to produce a very precise control of the arc through a broad wire feed speed range. With precise control of arc dynamics, Pulsed Current Metal Inert Gas Welding can be used as a fast-follow process at high travel speeds, or it can be run as a high deposition rate, fast-fill process. A variation of the spray transfer mode, pulse-spray is based on the principles of spray transfer but uses a pulsing current to melt the filler wire and allow one small molten droplet to fall with each pulse. This feature of current pulsating reduces net heat input to the base metal, so decreases undesirable effects of comparatively high heat input in MIG welding. The main setting parameters which influence weld quality or wire melting are background current "I_b, peak current I_p, background time T_b, and peak time T_p.". Pulsed Current Metal Inert Gas Welding is commonly used for root pass welding of tubes and pipe welding.

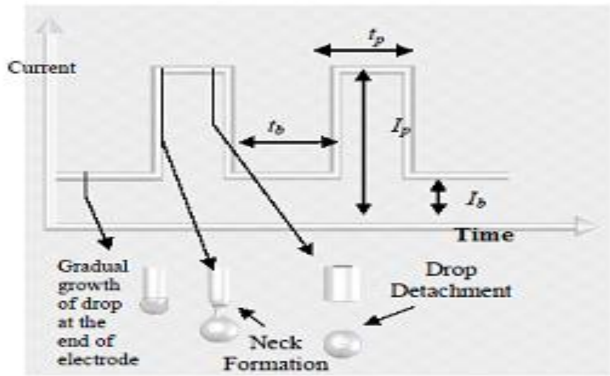

Fig-1: Pulse metal transfer phenomenon

2. LITERATURE REVIEW

S.V Sapakal et al. **[1]** presented a research on the optimization of MIG welding parameters using Taguchi design method. In their research they considered welding current, welding voltage and welding speed as input variables and penetration depth as output variable. MS C20 was selected as work piece material. 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) were employed to investigate the welding characteristics of MS C20 material and optimize the welding parameters. Their experimentation results that the lower current.

L. Suresh Kumar et al. **[2]** have investigated for welding aspects of AISI 304 & 316 by Taguchi technique for the process of TIG & MIG welding. Mechanical properties of austenitic stainless steel for the process of TIG and MIG welding have discussed here. The voltage has taken constant and various characteristics such as strength, hardness, ductility, grain structure, tensile strength breaking point, HAZ have observed in these two processes.

S.R. Meshram et al. **[3]** have done a research on optimization of process parameters of gas metal arc welding to improve the quality of weld bead geometry. In their work, a grey-based Taguchi method was adopted to optimize the gas metal arc welding process parameters. Many quality characteristic parameters were combined into one integrated quality parameter by using grey relational grade or rank. The welding parameters considered in their research were arc voltage, wire feed rate, welding speed, nozzle to plate distance and gas flow. The quality characteristics consider were penetration, reinforcement and bead width. Analysis of variance has performed to find the effect of individual process parameter on quality parameters. The Taguchi L_{25} array was adopted to conduct the experiments. The stainless steel (AISI410) was used as welding specimen.

Pawan Kumar et al. **[4]** have obtained the use of Taguchi's parameter design methodology for parametric study of Gas Metal Arc Welding of Stainless Steel & Low Carbon Steel. The input process variables considered here include welding current, welding voltage and gas flow rate. A total no. of 9 experimental runs were conducted using an L9 orthogonal array, and calculate the signal-to-noise ratio. Subsequently, using Analysis Of Variance (ANOVA) the significant coefficients for each input parameter on tensile strength & Hardness (PM, WZ & HAZ) were determined

A.K. Panday, Moeed et al. **[5]** performed their analysis on optimization of resistance spot welding parameters using Taguchi method. The experiments were conducted under varying pressure, welding current and welding time. The output characteristic considered was tensile strength of the welded joint. The material used was low carbon steel sheets of 0.9mm. Their conclusion leads that the contribution of welding current holding time and pressure towards tensile strength is 61%, 28.7% and 4 % respectively as determined by the ANOVA method.

S.R Patil et al. **[6]** presented their work on optimization of MIG welding parameters for improving welding strength. They presents the influence of welding parameters welding current, welding voltage, welding speed on ultimate strength of welded joints of AISI mild steel materials. A plan of experiments using Taguchi has decided. Experiments were performed and result was confirmed. From this study they concluded that the welding current and welding speed are the major factors affecting tensile strength of welded joints

Ajit hooda et al. **[7]** has done their research on optimization of MIG welding parameters in order to improve yield strength of AISI 1040 mild steel. The process parameters welding current, voltage, gas flow rate and wire speed were studied. The experiments were conducted based on four factors, three level orthogonal arrays. The empirical relationship can be used to predict the yield strength of welded material.

In the present work, it is planned to analyze the different input parameters in Pulsed Current Metal Inert Gas Welding to improve both Ultimate Tensile Strength and Hardness of the welding joint using Taguchi's orthogonal array and Grey Relational Analysis.

3. EXPERIMENTAL SETUP

The experiments have been conducted using a Pulsed Current Lorch welding machine having 400 Amperes maximum current with air type cooling and automated welding set up. In this welding machine automated Metal Inert Gas torches as well as automatic wire feeding units have provided.

3.1 Material selection

The present study has been carried out with ASTM A106 pipes is the standard specification for seamless carbon steel pipes for high-temperature service. Most common uses are in refineries and plants when gasses or fluids are transported at high temperatures and pressures.

Table -1: Chemical composition of ASTM A106 Pipe

Elements	**C**	**Mn**	**P**	**Si**	**S**	**Cr**	**Ni**
%	0.30	0.29	0.035	0.1	0.035	0.4	0.4

3.2 Proposed Design of Experiment

For the present investigation, three number of process parameters or control factors each having three levels is taken into consideration. The L_{27} orthogonal array was used.

3.3 Experimental parameter

Input parameters: Welding current, gas flow rate and wire feed rate.
Output parameters: Ultimate Tensile strength (UTS) and Hardness.

Table -2: Control Factors and their level

Symbol	**Parameters**	**Unit**	Levels		
			1	**2**	**3**
A	**Welding Current**	**Ampere**	55	60	65
B	**Gas Flow Rate**	**l/min**	12	13	14

C	**Wire Feed Rate**	**mm/min**	110	115	120

3.4 Taguchi Methodology

The Taguchi method developed by Genuchi Taguchi is a statistical method used to improve the product quality. Optimization of process parameters is the key step in the Taguchi method for achieving high quality without increasing cost. This is because optimization of process parameters can improve quality characteristics and the optimal process parameters obtained from the Taguchi method are insensitive to the variation of environmental conditions and other noise factors. Basically, classical process parameter design is complex and not easy to use. A large number of experiments have to be carried out when the number of 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. 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 loss function is further transformed into signal-to-noise (S/N) ratio.

3.4.1 S/N Ratio

The Signal to Noise ratios (S/N), which are log functions of desired output, serve as the objective functions for optimization, help in data analysis and the prediction of the optimum results. There are 2 Signal-to-Noise ratios of common interest for optimization of Static Problems.

1. Smaller the better is given by $\boldsymbol{\eta = -10 \log [(\Sigma Y_i^2/n]}$
2. Larger the better is given by $\boldsymbol{\eta = -10 \log [(\Sigma 1/Y_i^2)/ n]}$
Where, η = Signal to Noise ratio
Y_i= i^{th} observed value of response
n = no. of observations in a trial
y = average of observed response.

3.5 Experimental Work

Experiments were conducted using Pulsed Current Lorch welding machine by DC electrode positive power supply. Test pieces of size outer diameter of 25 mm, length 300 mm with wall thickness of 3mm were cut in to length of each 150 mm initially with an edge preparation of 45 degree and tack welded. Copper coated Mild steel electrode of 1.2 mm diameter was used for welding. Argon (85%) and CO_2 (15%) gas mixture was used for shielding. Welding speed (157 mm/min) has been kept constant for all twenty trails. Single pass welding was performed on pipes by varying the initial parameters. The working ranges for the process parameters were selected from the American Welding Society handbook.

Based on the designed L_{27} orthogonal array combination a series of joining processes was performed in welding machine. The photograph of the pulsed current Lorch welding machine is shown in Fig-2. Ultimate Tensile Strength and hardness are considered as objectives. For the calculation of the responses i.e. Ultimate Tensile Strength and hardness of welded specimens, tensile test were performed using Advanced Universal Testing Machine model number; AI UTS-1000 kN and make; Akash Industries. Hardness test was performed using Vickers hardness testing machine. The results of Ultimate Tensile Strength and hardness are shown in table 3.

Fig-2: Lorch Pulsed MIG Welding Machine

Fig-3: Welded ASTM A106 Pipes

Table -3*:* Experimental Results

No. of runs	Welding Current	Gas Flow Rate	Wire Feed Rate	UTS (N/mm^2)	Hardness (VHN)
1	55	12	110	303	102.83
2	55	12	115	235	103.83

3	55	12	120	207	111.91
4	55	13	110	215	106.3
5	55	13	115	204	102.56
6	55	13	120	225	112.9
7	55	14	110	195	108.34
8	55	14	115	232	112.07
9	55	14	120	172	118.23
10	60	12	110	258	102.71
11	60	12	115	229	104.44
12	60	12	120	245	113.18
13	60	13	110	210	104.4
14	60	13	115	256	114.35
15	60	13	120	189	117.9
16	60	14	110	250	110.3
17	60	14	115	202	112.07
18	60	14	120	162	118.23
19	65	12	110	306	107.35
20	65	12	115	375	108.89
21	65	12	120	255	111.69
22	65	13	110	335	114.87
23	65	13	115	276	112.07
24	65	13	120	209	113.56
25	65	14	110	245	108.91
26	65	14	115	251	114.44
27	65	14	120	256	127.2

4. GREY RELATIONAL ANALYSIS

The Grey Relational Analysis (GRA) associated with the Taguchi method represents a rather new approach to optimization. A system for which the relevant information is completely known is a white system, while a system for which the relevant information is completely unknown is black system. Any system between these limits is a grey system having poor and limited information.

4.1 Data Pre –Processing

Data Pre-Processing is normally required, since the range and unit in one data sequence may differ from others. It is also necessary when the sequence scatter range is too large, or when the directions of the target in the sequences are different.

For the "larger-the-better" characteristic like Ultimate Tensile Strength, the original sequence can be normalized as follows:

$$X_i^*(k) = \frac{X_i(k) - Min(k)}{Max\, X_i(K) - Min\, X_i(k)} \quad \text{(Eq. 1)}$$

Where, $X_i^*(k)$ and $X_i(k)$ are the sequence after the data preprocessing and comparability sequence respectively. i=1, 2, 3…n for experiment numbers 1 to n^{th} experiment.

When the form "Smaller-the-better" becomes the expected value of the data sequence, the original sequence can be normalized as,

$$X_i^*(k) = \frac{Max\, X_i(k) - X_i(k)}{Max\, X_i(K) - Min\, X_i(k)} \quad \text{(Eq. 2)}$$

By normalizing, Grey Relational Co-efficient (GRC) is calculated as;

$$\xi_i(k) = \frac{\Delta_{min} + \xi\Delta_{max}}{\Delta_{0i}(k) + \xi\Delta_{max}} \quad \text{(Eq. 3)}$$

$$\Delta_{0i}(k) = \| X^*_0(k) - X^*_i(k) \|$$

Where $\Delta_{0i}(k)$ is the deviation sequence of the reference sequence $X^*_0(k)$ and the comparability sequence is $X^*_i(k)$, ξ is the distinguishing or identification coefficient. If all the parameters are given equal preference, is taken as 0.5.

After obtaining the grey relational coefficient, the grey relational grade is computed by averaging the grey relational coefficient corresponding to each performance characteristic. The overall evaluation of the multiple performance characteristics is based on the grey relational grade which is given in equation 4.

$$\gamma_i = 1/n \sum_{k=1}^{n} \xi_i(k) \quad \text{(Eq. 4)}$$

Where γ_i the grey relational grade for the i^{th} experiment and **n** is the number of performance characteristics. The higher grey relational grade represents that the corresponding experimental result is closer to the ideally normalized.

4.2 Grey Relational Calculation for Multi Response

Table- 4: Normalized Value and deviation sequences for both UTS and Hardness

Expt. No.	Normalized Values		Deviation Sequences	
	UTS	Hardness	$\Delta_{0i}(1)$	$\Delta_{0i}(2)$
1	0.5953	0.0109	0.4046	0.9890
2	0.4219	0.0515	0.5780	0.9484
3	0.2601	0.3794	0.7398	0.6205
4	0.3063	0.1517	0.6936	0.8482
5	0.2427	0	0.7572	1
6	0.3641	0.4196	0.6358	0.5803
7	0.1907	0.2345	0.8092	0.7654
8	0.4046	0.3859	0.5953	0.6140
9	0.0578	0.6359	0.9497	0.3640
10	0.5549	0.0060	0.4450	0.9939
11	0.3872	0.0762	0.6127	0.9237
12	0.4797	0.4310	0.5202	0.5689
13	0.277457	0.074675	0.7225	0.9253
14	0.543353	0.47849	0.4566	0.5215
15	0.1560	0.62253	0.8439	0.3774
16	0.5086	0.3141	0.4913	0.6858
17	0.2312	0.3859	0.7687	0.6140
18	0	0.6359	1	0.3640
19	0.6531	0.1943	0.3468	0.8056
20	0.9132	0.2568	0.0867	0.7431
21	0.5375	0.3705	0.4624	0.6294
22	1	0.4995	0	0.5004
23	0.6589	0.3859	0.3410	0.6140
24	0.2716	0.4464	0.7283	0.5535
25	0.4797	0.2577	0.5202	0.7422
26	0.5144	0.4821	0.4855	0.5178
27	0.6416	1	0.3583	0

After data pre-processing is carried out, a grey relational coefficient can be calculated with the pre-processed sequence. It expresses the relationship between the ideal and actual normalized experimental results. The grey relational coefficient and Grade Relational Grade is given in equations 3 and 4

Table -5: The calculated grey relational grade and its order in the optimization process

Expt. No.	Grey Relational Coefficient		Grey Relational Grade	Rank
	UTS $\xi_i(1)$	Hardness $\xi_i(2)$		
1	0.552716	0.335786	0.444251	17
2	0.463807	0.345195	0.404501	22
3	0.403263	0.446215	0.424739	19
4	0.418886	0.370861	0.394874	24

5	0.397701	0.333333	0.365517	27
6	0.440204	0.46281	0.451507	15
7	0.381898	0.395125	0.388512	25
8	0.456464	0.448816	0.45264	14
9	0.346693	0.578675	0.462684	12
10	0.529052	0.334692	0.431872	19
11	0.449351	0.351197	0.400274	22
12	0.490085	0.46773	0.478907	9
13	0.408983	0.350797	0.37989	26
14	0.522659	0.489472	0.506065	5
15	0.372043	0.569843	0.470943	10
16	0.504373	0.421629	0.463001	11
17	0.394077	0.448816	0.421447	20
18	0.333333	0.578675	0.456004	13
19	0.590444	0.382965	0.486705	7
20	0.852217	0.40222	0.627218	3
21	0.51952	0.442688	0.481104	8
22	1	0.499797	0.749899	2
23	0.594502	0.44816	0.521659	4
24	0.407059	0.474576	0.440818	18
25	0.490085	0.402483	0.446284	16
26	0.507331	0.491228	0.49928	6
27	0.582492	1	0.791246	1

Since the experimental design is orthogonal, it is then possible to separate out the effect of each machining parameter on the grey relational grade at different levels. For example, the mean of the grey relational grade for the Current at levels 1, 2 and 3 can be calculated by averaging the grey relational grade for the experiments 1 to 9, 10 to 18 and 19 to 27 respectively as shown in Table 5. The mean of the grey relational grade for each level of the other welding parameters, namely, Current, Gas Flow Rate and Wire Feed Rate can be computed in the same manner. The mean of the grey relational grade for each level of the welding parameters is summarized and shown in Table 6.

Table- 6: Response table for the Grey Relational Grade

Levels	Current (A)	Gas Flow Rate (B)	Wire Feed Rate (C)
1	0.40129	0.46023	0.46503
2	0.45423	0.47568	0.48048
3	**0.57134**	**0.48678**	**0.49533**
Delta	0.17005	0.02655	0.0303
Rank	1	3	2

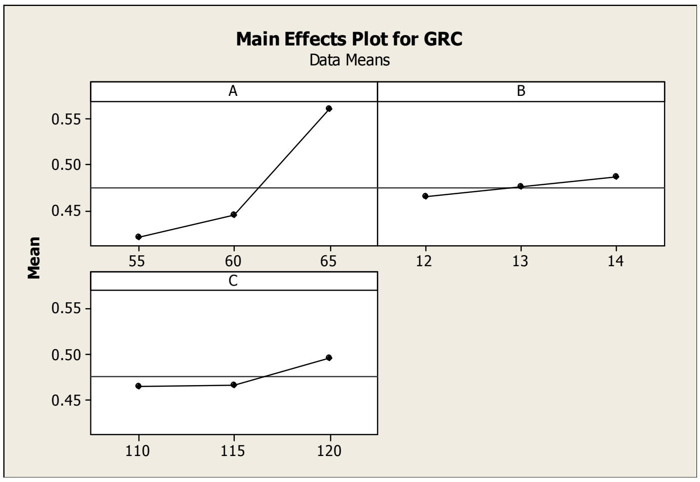

Figure -4: Main effect plots for Grey Relational Grade

4.3 Analysis of Variance for Grey Relational Grade

As we know that Analysis of Variance (ANOVA) is a statistical model which can be used for find out effect of independent parameter on single dependent parameter and also it can be useful to find out the significant welding parameters and the percentage contribution (%C) of each parameter. This method was applied to analyze grey relational grade for find

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out effect of each parameter on multi objective optimization. By use of Minitab 16 statistical software the analyzed value of ANOVA analysis for multi response optimization for Pulsed Current Metal Inert Gas Welding shown in Table 7.

Table -7: ANOVA Grey Relational Grade

Source	DOF	Seq SS	Adj MS	F	% C
A	2	0.152709	0.49925	6.54	58.7
B	2	0.005251	0.00112	2.41	2.02
C	2	0.099849	0.00262	3.12	38.3
Error	20	0.00225	0.00764	-	0.86
Total	26	0.260066	-	-	100

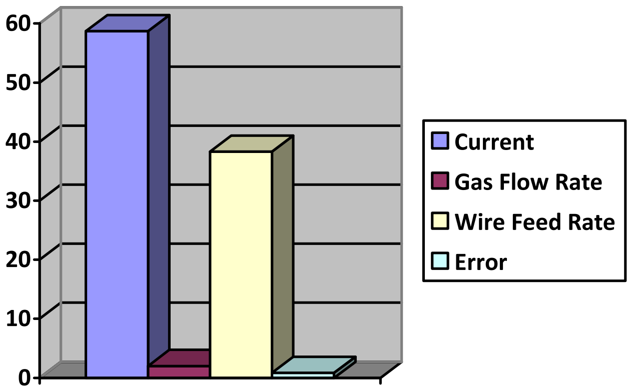

Figure -5: Percentage contributions of factors on the grey relational grade

Percentage contributions for each term affecting grey relational grade are shown in Figure 5. The figure clearly shows that welding Current is the most contributing parameter that affects grey relational grade and hence contributes in improving Ultimate Tensile Strength and Hardness.

5. CONFIRMATION TEST

Confirmation test has been carried out to verify the improvement of performance characteristics in Pulsed Current Metal Inert Gas Welding ASTM A106 Pipes using same experimental setup. The optimum parameters are selected for the confirmation test as presented in Table 8.

Table -8: Results of confirmation experiment.

Condition description	Initial Set of parameters	Optimal welding parameters in Twenty Seven trial of Orthogonal array
Level	A1B2C3	A3B3C3
UTS (N/mm²)	225	381
Hardness (VHN)	119.2	130.2

From Table 8, which shows the comparison of the experimental results using the initial OA **(A3B2C3)** and optimal grey theory prediction design **(A3B3C3)** welding parameters. From Table 8, Ultimate Tensile Strength is accelerated from 225 to 381 N/mm² similarly; Hardness is increased from 119.2 to 130.08 VHN. The corresponding improvements in UTS and Hardness are 40.94 % and 8.36 % respectively. It is clearly shown that the multiple performance characteristics in the Pulsed Current Metal Inert Gas Welding process are greatly improved through this study.

6. RESULT AND DISCUSSION

Here above from the ANOVA table for Grey Relational Grade we come to know that the most significant parameter which affects UTS and Hardness value of welding joint is welding Current and the least significant is Gas Flow Rate. But our main aim in the study to get the optimize value of input parameters for combine responses. It is done by making the response table according to Taguchi method for grey relational grades values which is shown as in table 5. From the study of Grey relational grades analysis, we comes to know that for optimum welding parameters for maximization of Ultimate Tensile Strength and Hardness are welding Current is at third highest level **(65 Ampere)**, Gas Flow Rate is at the third highest level **(14 l/min)** and Wire Feed Rate is also at the third highest level **(120 mm/min)** The best combination of welding parameters is **A3B3C3** for best results. The parameter which is most significant for both responses simultaneously is welding Current and Gas Flow Rate is the least significant within all three.

7. CONCLUSION

The experiment designed by Taguchi method fulfills the desired objective. Grey Relational Analysis been used to find out the Multi Response Performance (MRP) of the best combination of Ultimate Tensile Strength and Hardness. Analysis of Variance (ANOVA) helps to find out the significance level of the each parameter. The optimum value was predicted using MINITAB-16 software. Welding current **65 Ampere**, Gas Flow Rate **14 l/min** and Wire Feed Rate **120 mm/min** have the optimal value of control factors for maximum UTS and Hardness. The experimental results confirmed the validity of the used Taguchi method for enhancing the welding performance and optimizing the welding parameters in Pulsed Current Metal Inert Gas Welding.

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REFERENCES

[1] S.V Sapkal, M.T Telsang (2012),Parametric optimization of MIG welding using Taguchi design method. International Journal Of advanced Engineering Research and Studies, pp. 28-30.

[2] L. Suresh Kumar, S. M. Verma, P. Radhakrishna Prasad, P. Kirankumar, T. SivaShanker (2011) "Experimental investigation for welding aspects of AISI 304 & 316 by Taguchi technique for the process of TIG & MIG welding", International Journal of Engineering Trends and Technology, vol. 2, no. 2, pp. 28-33.

[3] S.R. Meshram, N.S. pohokar, (2013), Optimization of process parameters of Gas Metal Arc Welding to improve Quality of Weld bead geometry. International journal of Engineering, Business and Enterprise Applications, pp. 46-52.

[4] Pawan Kumar, B. K. Roy, Nishant (2013) "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, no. 4, pp. 18-22.

[5] [4] A.K. Panday, M.I. Khan, K.M. Moeed, (2013), Optimization of resistance welding parameters using Taguchi method. International Journal of Engineering Science and Technology, pp. 243-240.

[6] [6] S.R. Patil, C.A. Waghmare, (2013), Optimization of MIG welding parameters for improving strength of welded joints. International Journal of Advanced Engineering and Studies, pp.14-16.

[7] Ajit Hooda, Ashwani Dhingra and Satpal Sharma, (2012),Optimization of Welding process parameters to predict maximum yield strength in AISI 1040. International Journal of mechanical Engineering and Robotics Research India, pp. 204-212.

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