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Optimization of Process Parameters in Synergic MIG Welding of Mild Steel

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Abstract — **MIG Welding is compatible with continuous welding of all commercial metals and it can be adapted in mechanized as well as robotic applications. Therefore efficient optimization of machining parameters can produce high-quality products with low cost and high productivity. The experimental study is carried out to optimize various control factors to achieve the best results of Synergic MIG welding on Mild Steel. Design of Experiment, which is an orthogonal array, is formed using Minitab 16.0. Using Taguchi's parameter design, three control parameters affecting the desired weld quality viz. traverse speed (Vt), welding voltage (V) and wire feed rate (F) were selected with three levels selected for each factor. The process' output characteristics include bead width (W), bead height (H), penetration (P), heat affected zone (HAZ) and hardness (HRB). Observed weld bead features are useful in deciding the strength of the bead formed. Based on the mathematical values of these an optimum combination of welding parameters is found. Finally, Grey relational analysis, a popular evolutionary approach to uncertainty, multi-input, discrete data problem, is applied to determine the suitable selection of machining parameters for MIG process. The effect of each control factor on the performance measure is studied individually using various plots.**

The study demonstrates that the combination of welding parameters can be optimized so as to achieve better metal deposition rate, bead geometry, Shape factor, Form factor using Taguchi design optimization and Grey relational analysis.

Keywords: Synergic MIG, Traverse speed, Welding Voltage, Wire Feed Rate, Bead geometry, Design of Experiment, Taguchi method, Grey Relational analysis

1. INTRODUCTION

Metal Inert Gas Welding of mild steel is a process in which the source of heat is an arc formed between consumable metal electrode and the work piece, and the arc and the molten puddle are protected from contamination by the atmosphere (i.e. oxygen and nitrogen) with an externally supplied gaseous shield of active gases such as carbon dioxide, argon-carbon dioxide mixture, which is chemically active or not inert.
Synergic MIG, an advanced welding system, incorporates both Spray and pulse transfer and provides complete range of high technology digital microprocessor controlled equipment.

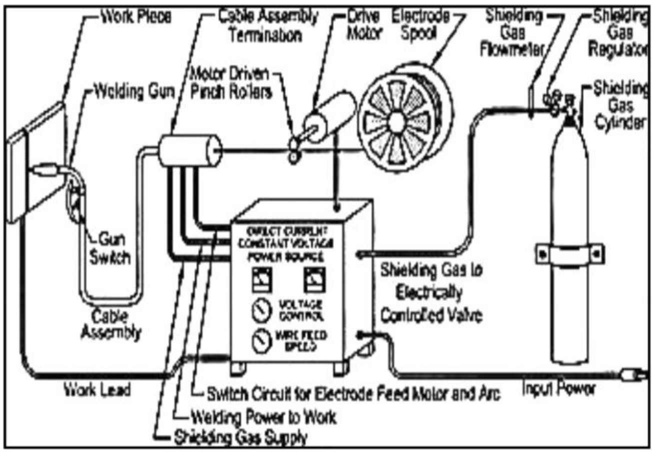

Fig. 1: Schematic diagram of Experimental setup

This welding process overcomes the restriction of using small lengths of electrodes to overcome the inability of the submerged-arc process of welding in various positions. By suitably adjusting the process parameters, it is possible to weld joints in the thickness range of 1-13 mm in all welding positions.

The quality of any weld process is characterized by the weld bead distortion, mechanical properties and weld bead geometry (as shown in fig. 2). Out of these factors, the weld bead geometry is the easiest to measure and control. Thus by controlling the weld bead geometry we can successfully control the weld quality. Therefore, the complex relationship between the process variables and the weld bead geometry necessitates a robust mathematical approach i.e. Taguchi method to quantify the relationship between them.
Optimum conditions can be established for a range of applications which are readily reproduced by the welder. However, certain important points must be considered in order to enhance the working accuracy. Researchers have many attempts to predict the process parameters of submerged arc welding to get smooth quality of weld.

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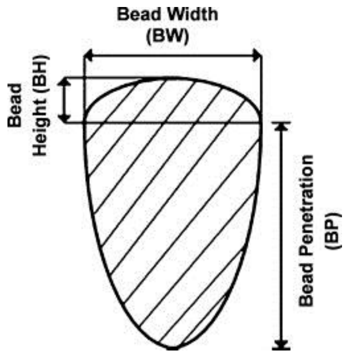

Fig. 2: Bead Geometry

ManiharSingh, AbhijitSaha [1] worked on optimization of welding parameters for maximization of weld bead widths for submerged arc welding of mild steel plates. Taguchi's philosophy has been applied for obtaining optimal parametric combinations to achieve desired weld bead geometry and dimensions related to heat affected zone. H.J. Park, D.C. Kim,M.J. Kang, S. Rhee [2] worked on optimization of the wire feed rate during pulse MIG welding of Al sheets. Welding experiments were conducted with various wire feed speeds of 0.5 m/min, 1.0 m/min, and 1.5 m/min, and the bead characteristics were evaluated along with shape factors for the weld bead, the bead width was measured. It concluded that with the increase of the welding speed (on aluminum sheet) the corresponding wire feed speed should increase as well. SauravDatta, Asish Bandyopadhyay, Pradip Kumar Pal [3] used Grey-based taguchi method for optimization of bead geometry in submerged arc bead-on-plate welding. A multi-response optimization problem has been developed in search of an optimal parametric combination to yield favorable bead geometry of submerged arc bead-on-plate weld.K. Abbasi, S. Alam, Dr. M.I. Khan [4] studied the effect of MIG welding parameters on the Weld-Bead shape characteristics. The depth of penetration and weld width were measured for each specimen after the welding operation. Effect of welding speed and heat input rate on depth of penetration and weld width were also investigated.

The most important performance parameters in Synergic MIG welding are metal deposition rate (MDR), bead height (BH), bead width (BW) and weld zones hardness (HRB). The other dependent parameters include penetration shape factor (PSF), Heat affected zone and reinforcement form factor (RFF).
In Synergic MIG operations, material deposition rate determines the economies of machining and rate of production whereas bead geometry denotes quality of the weld. In setting the machining parameters, the goal is: the maximization of MDR, maximization of HRB, maximization of PSF, maximization of RFF, minimization of BH.

2. EXPERIMENTAL SETUP

The experiments were performed on PHOENIX 521 EXPERT PLUS force arc welding machine, which is manufactured by EWM high-tech welding technologies. Welding machine is capable of choosing the current curve when the welder has set the wire speed, the metal alloy, the wire diameter and the shielding gas. That is the welding equipment controls the base current, the form and number of the current pulsations. The synergic capability enables all of the welding parameters to be controlled from a signal dial control which optimizes the current peak pulse and background values, the voltage, wire feed speed. It has also become possible to reprogram the power source instantly when wire size, shield gas, filler metal composition, etc. are changed simply by dialing in a program number. These programs have been established by the equipment manufacturer with the optimum parameters for the application.

3. PLAN OF INVESTIGATION

The main aim of the project is investigation and statistical analysis of process variables on the bead geometry of Synergic MIG Welding and to find out the optimum combination of process parameters. To achieve the above mentioned objectives, following are the sequence of steps which are carried out:

1. Identification of important process parameters.
2. Deciding the working range of the process parameters, viz. wire feed rate (f), welding voltage (V), and Traverse Speed (V_T).
3. Developing the L_9 design matrix.
4. Conducting the experiments as per the design matrix.
5. Recording the responses viz. bead height (BH), bead width (BW) and bead penetration (P) and calculating penetration shape factor and reinforcement form factor.
6. Identification of the optimum values of the process parameters.
7. Plotting the graphs and drawing conclusions.
8. Discussion of the results.

3.1 Identification of important process parameters

Based on the effect on weld bead geometry, ease of control and capability of being maintained at the desired level, three independently controllable process parameters were identified namely, the welding Voltage (V), the traverse speed (V_t), and wire feed rate (F) at constant nozzle to plate distance.

3.2 Selection of working range of design parameters

Trial runs were conducted by varying the process parameters at a time. The working range was fixed by literature review, some experience and some preliminary investigations. The upper and lower levels were decided based on trial runs conducted at extreme limits and an intermediate level was selected where better results were obtained.

Table 1: Selection of levels of Process Parameters

Levels	L1	L2	L3
VOLTAGE	21.1	23.2	24.3
FEED RATE	2.2	3.4	4.2
TRAVERSE SPEED	5.93	7.75	9.15

3.3 Developing the design of experiment

Generally, the machine tool builder provides machine parameter table to be used for setting input parameters. This process relies heavily on the experience of the operators. In practice, it makes very difficult to utilize the optimal functions of a machine owing to there being too many adjustable process parameters. With an objective to alleviate this difficulty, a simple but reliable method based on statistically designed

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experiments is suggested for investigating the effects of various process parameters on MDR, HRB, bead Geometry and determines optimal process settings. The Taguchi method, a powerful experimental design tool, uses simple, effective, systematic approach for deriving of the optimal process parameters. Further this approach requires minimum experimental cost and efficiently reduces the effect of source of variation. However, this optimization should be performed in such a way that all the objectives are fulfilled simultaneously. Such an optimization technique is called multi-response optimization.

Table 2: Input Values for Taguchi Design of Experiments

Exp. No.	Voltage (Volts)	Feed Rate (mm/s)	Traverse Speed (mm/s)
1	21.1	2.2	5.93
2	21.1	3.4	7.75
3	21.1	4.2	9.15
4	23.2	2.2	7.75
5	23.2	3.4	7.75
6	23.2	4.2	5.93
7	24.3	2.2	9.15
8	24.3	3.4	5.93
9	24.3	4.2	7.75

The method utilizes a well-balanced experimental design which allows a limited number of experimental runs called as Orthogonal array design and signal-to-noise ratio (S/N ratio/ SNR), which serves the objective function to be optimized (maximized) within experimental domain. The control factors are used to select the best conditions for stability in design of manufacturing process, whereas noise factors denote all factors that cause vibrations. In this study we applied a Taguchi L_9 orthogonal array to plan the experiments on MIG welding process. Three controlling factors viz. traverse speed (V_T), welding voltage (V) and wire feed rate (F) with three levels for each factor were selected.

However, traditional Taguchi method cannot solve multi-objective optimization problem. To overcome this, the Taguchi method was coupled with Grey relational analysis. This approach can solve multi-response optimization problem simultaneously.

3.4 Conducting the Experiment

Various welding parameters throughout the experiment are as follows:

Table 3: Parameters of the setting

Control Factors	Fixed Parameters	
Welding Voltage(V)	NTD (mm)	17.5 mm
	Stick Out (mm)	16 mm
	Wire Diameter (mm)	1.2 mm
Wire feed rate(F)	Shielding gas	CO_2
	Angle of welding gun	60-70 degree
Traverse Speed(V_T)	Shape of w/pc	Rectangular
	Thickness of w/pc	5 mm

The Grey relational analysis is then applied to examine how the welding process factors influence the bead width (BW), reinforcement height (BH), penetration (P) and HAZ, as well as weld hardness (HRB). The Grey theory can provide solution to a system in which the model is unsure or the information is incomplete. Besides, it provides an efficient solution to the uncertainty, multi-input and discrete data problem. According to the Taguchi quality design concept, a L9 mixed-orthogonal-array table was chosen for the experiments. With Grey relational analysis, it is found that the wire feed rate has a significant influence on the machining speed. Moreover, the optimal machining parameters setting for maximum MDR and minimum PSF, RFF can be obtained. The process called as Grey relational generating is next followed to find the grey relational grade for each performance characteristic. Using grey relational grades for each characteristic, we found the rank of our output from optimum to less considerable.

4. EXPERIMENTAL PROCEDURE

Bead on plate technique was employed for depositing the weld beads on mild steel plate using semi mechanized welding station. For the experiment, three different parameters were taken; they are welding voltage, traverse speed and wire feed rate. By using Taguchi technique, 9 run orders were computed for three different levels. Correspondingly 9 plates cut each of dimensions 6 inch in length were cut. After cutting all plates, welding was carried out as per specified parameters for all plates individually. All experiments were carried out with a a contact-tip to work piece distance of 17.5 mm using the mixture of CO_2 as shielded gas. A DC power source was used to perform the bead on plate by means of synergic MIG process.

4.1 Optimization Using Grey Based Taguchi Method

- Metal Deposition Rate

Table 4: Response table for MDR's SNR

Level	Voltage (Volts)	Feed Rate (mm/s)	Traverse Speed(mm/s)
1	52.83	49.76	52.96
2	52.52	53.14	52.41
3	52.61	55.07	52.70
Delta	0.31	5.31	0.55
Rank	3	1	2

The response table and corresponding response graphs are shown for S/N ratio for MDR in table 4 and Fig. 3. The ranks obtained from the response table show that feed rates have the maximum effect on the MDR. The factors' levels viz. V(1), V_t(1), F(3) have the maximum S/N ratio.

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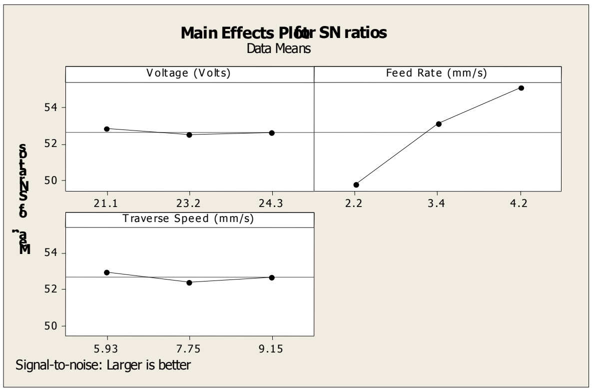

Fig. 3: SN Ratio of MDR for process parameters independently

Table 5: Grey Relational analysis for MDR

Exp.	MDR(mg/s)	x_i*(k)	Δ_0i(k)	γ(k)
1	314.7	0.0804	0.9196	0.3522
2	457.6	0.5467	0.4533	0.5245
3	584.2	0.9599	0.0401	0.9258
4	290.1	0.0000	1.000	0.3333
5	436.7	0.4785	0.5215	0.4895
6	596.5	1.0000	0.0000	1.000
7	318.8	0.0936	0.9064	0.3555
8	467.4	0.5787	0.4213	0.5427
9	522.9	0.7596	0.2404	0.6754

From the above graphs and rank obtained from response table it can be observed that the feed rate has the most significant effect on the MDR's SNR.

➢ Heat Affected Zone

Table 6: Response Table for HAZ's SNR

Level	Voltage (Volts)	Feed Rate (mm/s)	Traverse Speed(mm/s)
1	2.5830	4.6363	2.4580
2	0.2142	1.9475	1.1198
3	4.3013	0.5147	4.7213
Delta	4.0871	4.1216	3.6015
Rank	2	1	3

The response table and corresponding response graphs are shown for S/N ratio for HAZ in table 6 and Fig.5. The ranks obtained from the response table show that feed rates have the maximum effect on the HAZ .The factors' levels viz. V(3), V_t(3), F(1) have the maximum S/N ratio.

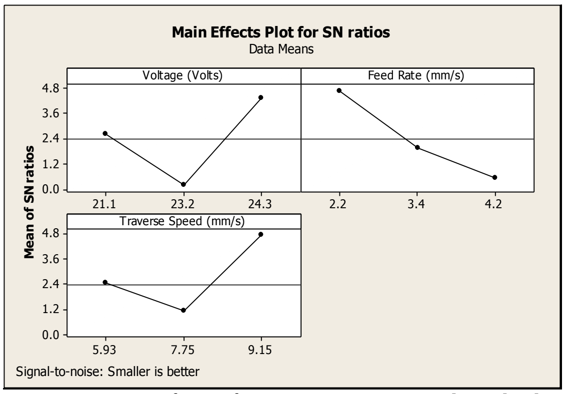

Fig. 4: SN Ratio of HAZ for process parameters independently

Table 7: Grey Relational analysis for HAZ

Exp. No.	HAZ			x_i*(k)	Δ_0i(k)	γ(k)
	B1	B2	Mean			
1	0.445	0.659	0.552	0.763	0.237	0.679
2	0.839	0.832	0.8355	0.373	0.627	0.444
3	0.769	1.008	0.8885	0.301	0.699	0.417
4	0.896	1.029	0.9625	0.199	0.801	0.384
5	0.703	1.041	0.872	0.323	0.677	0.425
6	1.129	1.084	1.1065	0.000	1.00	0.333
7	0.25	0.509	0.3795	1.00	0.000	1.00
8	0.698	0.703	0.7005	0.559	0.441	0.531
9	0.769	0.934	0.8515	0.351	0.649	0.435

➢ Bead Height

Table 8: Response Table for BH's SNR

Level	Voltage (Volts)	Feed Rate (mm/s)	Traverse Speed (mm/s)
1	-6.838	-4.641	-6.688
2	-6.903	-6.686	-6.566
3	-5.326	-7.740	-5.436
Delta	1.577	3.099	1.252
Rank	2	1	3

The response table and corresponding response graphs are shown for S/N ratio for BH in table 9 and Fig. 5. The ranks obtained from the response table show that feed rate has the maximum effect on the BH The factors' levels viz. V(3), V_t(3), F(1) have the maximum S/N ratio.

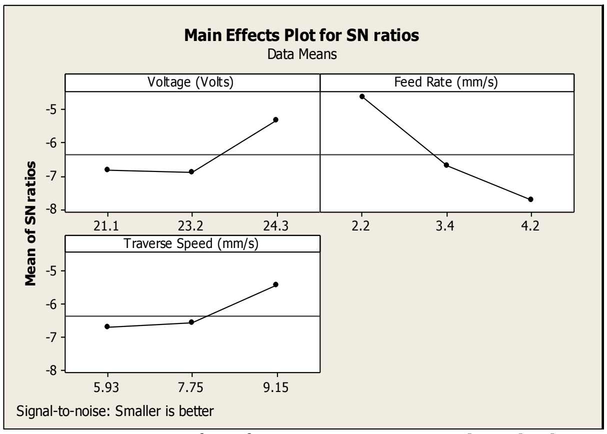

Fig. 5: SN Ratio of BH for Process Parameters Independently

Table 9: Grey Relational analysis for BH

Exp. No.	Bead Height			x_i*(k)	Δ_0i(k)	γ(k)
	B1	B2	Mean			
1	1.874	2.017	1.945	0.5525	0.4475	0.5277
2	2.178	2.223	2.201	0.3391	0.6609	0.4307
3	2.429	2.527	2.478	0.1067	0.8933	0.3589
4	1.744	1.875	1.809	0.6664	0.3336	0.5998
5	2.157	2.446	2.301	0.2545	0.7455	0.4014
6	2.603	2.608	2.605	0.0000	1.000	0.3333
7	1.688	1.134	1.411	1.000	0.0000	1.000
8	2.221	1.754	1.987	0.5174	0.4826	0.5089
9	2.338	2.15	2.244	0.3026	0.6974	0.4176

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➢ Penetration

Table 10: Response Table for Penetration's SNR

Level	Voltage (Volts)	Feed Rate (mm/s)	Traverse Speed(mm/s)
1	4.0902	0.2577	2.9817
2	3.3242	3.3257	3.7354
3	2.3065	6.1375	2.6381
Delta	1.7836	5.8798	1.0973
Rank	2	1	3

The response table and corresponding response graphs are shown for S/N ratio for Penetration in table 10 and Fig. 6. The ranks obtained from the response table shows that feed rate has the maximum effect on the Penetration. The factors' levels viz. V(3), $V_t(2)$, F(3) have the maximum S/N ratio.

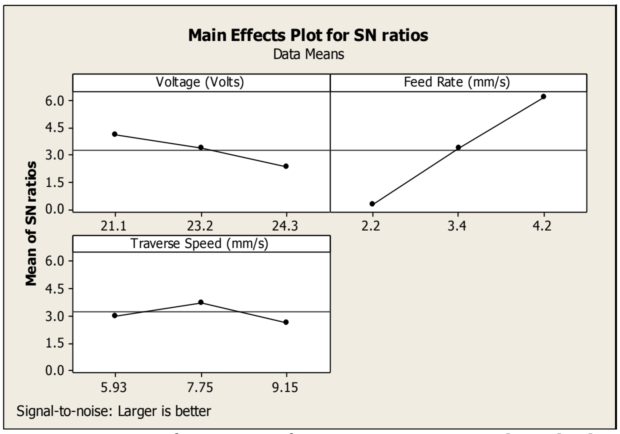

Fig. 6: SN Ratio of Penetration for process parameters independently

Table 11: Grey Relational analysis for Penetration

Exp No	Penetration			x_i*(k)	Δ_0i(k)	γ (k)
	B1	B2	Mean			
1	1.228	1.026	1.127	0.1911	0.8088	0.3820
2	1.824	1.785	1.804	0.7852	0.2148	0.6994
3	1.977	2.062	2.019	0.9737	0.0263	0.9500
4	1.183	0.951	1.067	0.1385	0.8614	0.3672
5	1.425	1.458	1.441	0.4669	0.5330	0.4840
6	1.699	2.400	2.049	1.000	0.0000	1.000
7	0.7680	1.050	0.909	0.0000	1.0000	0.3333
8	1.303	1.122	1.212	0.2661	0.7339	0.4052
9	2.182	1.843	2.012	0.9676	0.0324	0.9391

➢ Penetration Shape Factor

Table 12: Response Table for PSF's SNR

Level	Voltage (Volts)	Feed Rate (mm/s)	Traverse Speed(mm/s)
1	-7.963	-9.515	-9.911
2	-9.197	-9.417	-8.751
3	-10.349	-8.576	-8.894
Delta	2.385	0.939	1.161
Rank	1	3	2

The response table and corresponding response graphs are shown for S/N ratio for PSF in table 12 and Fig. 7. The ranks obtained from the response table shows that the voltage has the maximum effect on the PSF. The factors' levels viz. V(1), $V_t(2)$, F(3) have the maximum S/N ratio.

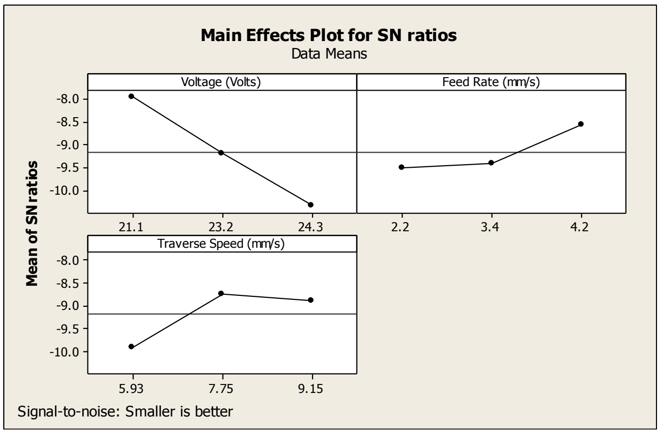

Fig. 7: SN Ratio of PSF for process parameters independently

Table 13: Grey Relational analysis for PSF

Exp. No.	W (mm)	P (mm)	PSF	x_i*(k)	Δ $_0$i(k)	γ (k)
1	5.167	1.127	4.585	0.4186	0.5814	0.4623
2	5.919	1.804	3.280	0.8183	0.1817	0.7334
3	5.427	2.019	2.688	1.000	0.0000	1.000
4	5.149	1.067	4.826	0.3448	0.6552	0.4328
5	6.093	1.441	4.227	0.5283	0.4717	0.5146
6	8.287	2.049	4.044	0.5844	0.4156	0.5461
7	4.994	0.909	5.494	0.1400	0.8600	0.3677
8	7.215	1.212	5.951	0.0000	1.000	0.3333
9	6.229	2.012	3.095	0.8751	0.1249	0.8001

➢ Reinforcement Form Factor

Table 14: Response Table for RFF's SNR

Level	Voltage (Volts)	Feed Rate (mm/s)	Traverse Speed(mm/s)
1	-7.963	-9.515	-9.911
2	-9.197	-9.417	-8.751
3	-10.349	-8.576	-8.894
Delta	2.385	0.939	1.161
Rank	1	3	2

The response table and corresponding response graphs are shown for S/N ratio for RFF in table 14 and Fig. 8. The ranks obtained from the response table shows that the voltage has the maximum effect on the RFF. The factors' levels viz. V(1), $V_t(2)$, F(3) have the maximum S/N ratio.

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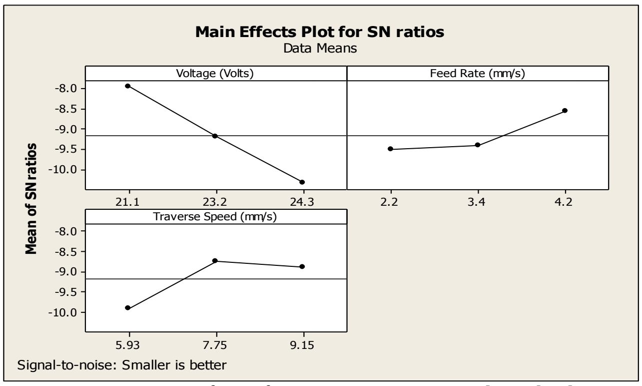

Fig.8: SN Ratio of RFF for Process Parameters independently

Table 15: Grey Relational analysis for RFF

Exp. No.	W (mm)	H (mm)	RFF	$x_i^*(k)$	$\Delta_{0i}(k)$	γ (k)
1	5.167	1.945	2.656	0.6767	0.3233	0.6073
2	5.919	2.201	2.690	0.6529	0.3470	0.5903
3	5.427	2.478	2.190	1.000	0.0000	1.000
4	5.149	1.809	2.846	0.5450	0.4550	0.5236
5	6.093	2.301	2.647	0.6826	0.3174	0.6117
6	8.287	2.605	3.180	0.3122	0.6878	0.4210
7	4.994	1.411	3.539	0.0633	0.9367	0.3480
8	7.215	1.987	3.630	0.0000	1.000	0.3333
9	6.229	2.244	2.776	0.5934	0.4066	0.5515

- Hardness of Weld Zone

Table 16: Response Table for Hardness's SNR

Level	Voltage (Volts)	Feed Rate (mm/s)	Traverse Speed(mm/s)
1	38.69	38.92	38.55
2	38.58	38.55	38.71
3	38.85	38.65	38.94
Delta	0.27	0.37	0.39
Rank	3	2	1

The response table and corresponding response graphs are shown for S/N ratio for hardness in table 16 and Fig. 9. The ranks obtained from the response table shows that the voltage has the maximum effect on the PSF. The factors' levels viz. V(1), $V_t(2)$, F(3) have the maximum S/N ratio.

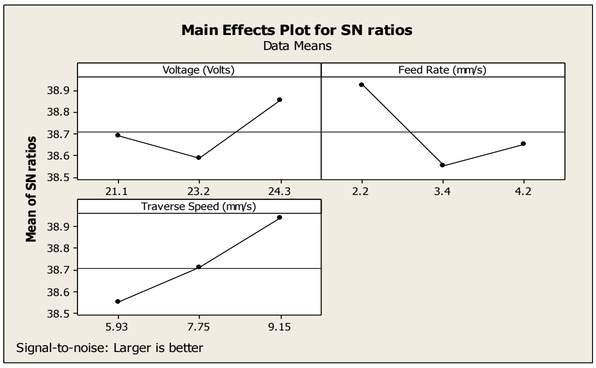

Fig. 9: SN Ratio of Hardness for process parameters independently

Exp. No.	HRB Weld Zone	$x_i^*(k)$	$\Delta_{0i}(K)$	γ (k)
1	87	0.63	0.38	0.57
2	84	0.25	0.75	0.40
3	87	0.63	0.38	0.57
4	88	0.75	0.25	0.67
5	85	0.38	0.63	0.44
6	82	0.00	1.0	0.33
7	90	1.0	0.00	1.0
8	85	0.38	0.62	0.44
9	88	0.75	0.25	0.67

Table 17: Grey Relational Analysis for HRB Number

GREY'S RELATIONAL GRADE is calculated by taking the mean of all the grey relational coefficients. Correspondingly, rank or order of the all experiments is calculated.

Table 18: Grey Relational Grade for all experiments

MDR	H	PSF	HAZ	P	RFF	HRB	Grade	Order
γ (k)	γ (k)	γ (k)	γ (k)	γ (k)	γ (k)	γ (k)		
0.352	0.527	0.462	0.678	0.382	0.607	0.571	0.512	6
0.524	0.430	0.733	0.443	0.699	0.590	0.400	0.546	5
0.925	0.359	1.000	0.416	0.949	1.000	0.571	0.746	1
0.333	0.599	0.432	0.384	0.367	0.523	0.667	0.473	8
0.489	0.401	0.514	0.424	0.483	0.611	0.444	0.481	7
1.000	0.333	0.546	0.333	1.000	0.420	0.333	0.567	4
0.355	1.000	0.367	1.00	0.333	0.347	1.00	0.629	3
0.542	0.508	0.333	0.531	0.405	0.333	0.444	0.443	9
0.675	0.417	0.800	0.435	0.938	0.551	0.667	0.641	2

5. RESULTS AND DISCUSSIONS

5.1 Prediction using Taguchi method

The Values of the output parameters is then predicted using MINITAB 16.0 to obtain values for the remaining 18 experiments. The accuracy obtained from this method is verified from the already available values to be as close to 95% and as precise as 99%. The obtained values (shown in table 19) are used to plot surface charts for the output parameters against other two control factors.

The following observations have been made about Metal Deposition Rate, Bead Height, Penetration, Penetration Shape Factor, Reinforcement Form Factor and Weld Zone Hardness.

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1) Metal Deposition Rate (MDR)

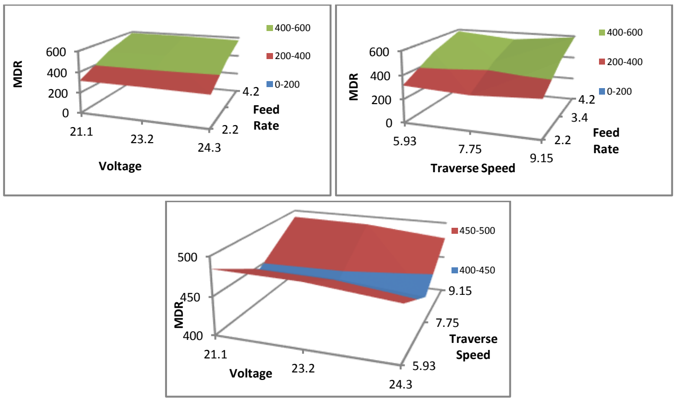

Fig. 10: Variation in MDR

MDR increases with increase in feed rate. It remains constant with Voltage and with Increase in Traverse Speed it decreases earlier but then shows an increasing trend.

Table 19: Prediction table for output parameters using Taguchi method

Voltage	Feed Rate	Traverse Speed	Predicted MDR	Predicted Bead Height	Predicted Penetration Shape Factor	Predicted Penetration	Predicted Reinforcement Form Factor	Predicted HRB
21.1	2.2	5.93	318.2	1.908	4.664	1.145	2.797	86.48
21.1	2.2	7.75	292.6	1.851	3.528	1.266	2.412	88.80
21.1	2.2	9.15	322.0	1.707	4.085	1.070	2.562	89.02
21.1	3.4	5.93	484.5	2.350	4.304	1.541	2.822	82.97
21.1	3.4	7.75	445.7	2.280	3.256	1.704	2.433	85.19
21.1	3.4	9.15	490.3	2.102	3.770	1.441	2.584	85.40
21.1	4.2	5.93	586.4	2.726	3.039	2.252	2.510	83.84
21.1	4.2	7.75	539.4	2.645	2.299	2.490	2.165	86.08
21.1	4.2	9.15	593.5	2.438	2.662	2.106	2.299	86.30
23.2	2.2	5.93	316.9	1.871	6.212	0.9910	3.290	85.53
23.2	2.2	7.75	291.5	1.815	4.699	1.096	2.836	87.81
23.2	2.2	9.15	320.7	1.673	5.441	0.9267	3.013	88.03
23.2	3.4	5.93	482.6	2.305	5.733	1.334	3.319	82.05
23.2	3.4	7.75	443.9	2.236	4.337	1.475	2.861	84.24
23.2	3.4	9.15	488.4	2.061	5.021	1.248	3.039	84.46
23.2	4.2	5.93	584.1	2.674	4.048	1.950	2.952	82.91
23.2	4.2	7.75	537.2	2.594	3.062	2.156	2.546	85.13
23.2	4.2	9.15	591.1	2.391	3.545	1.824	2.704	85.34
24.3	2.2	5.93	310.1	1.603	6.333	0.932	3.681	88.15
24.3	2.2	7.75	285.2	1.555	4.790	1.031	3.174	90.50
24.3	2.2	9.15	313.8	1.434	5.547	0.871	3.371	90.73
24.3	3.4	5.93	472.2	1.975	5.844	1.255	3.714	84.57
24.3	3.4	7.75	434.3	1.916	4.421	1.388	3.202	86.83
24.3	3.4	9.15	477.9	1.766	5.119	1.173	3.401	87.05
24.3	4.2	5.93	571.6	2.291	4.127	1.834	3.304	85.45
24.3	4.2	7.75	525.7	2.222	3.122	2.028	2.849	87.74
24.3	4.2	9.15	578.4	2.049	3.615	1.715	3.026	87.96

With increase in feed rate more metal is deposited and as a result metal deposition rate increases. It is expected that with increase in traverse speed MDR should increase but this negative effect of speed is due to the fact that when speed increases, the thermal energy transmitted to the base plate from the arc or line power per unit length of the weld bead decreases and less filler metal is deposited per unit length of weld bead, resulting in thinner and narrower weld bead.

2) Bead Height (BH)

This is consistent with the fact that on increasing the voltage the weld beads become more flatter, which in turn decreases the bead height. The reason for decrease in reinforcement height has been discussed in previous paragraph. As with increase in feed rate more amount of metal is deposited therefore bead height increases.

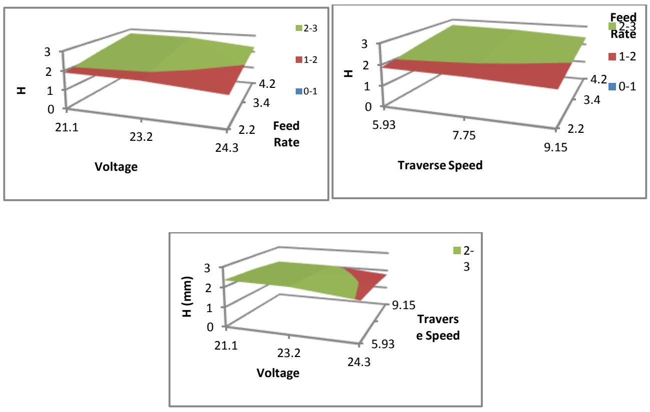

Fig. 11: Variation in Bead Height

Bead Height decreases with increase in Voltage and Traverse speed while it increases with increase in Feed Rate.

3) Penetration Shape Factor(PSF) and Reinforcement Form Factor(RFF)

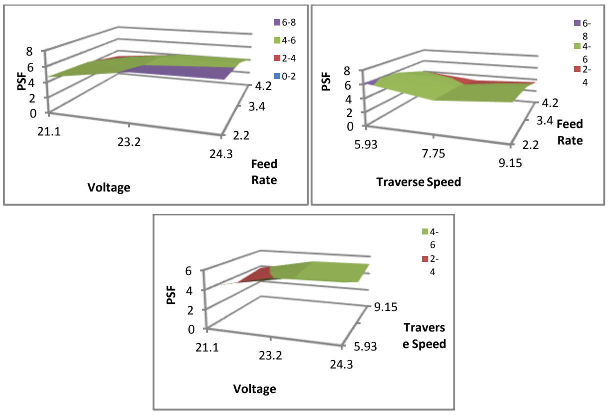

Fig. 12: Variation in PSF

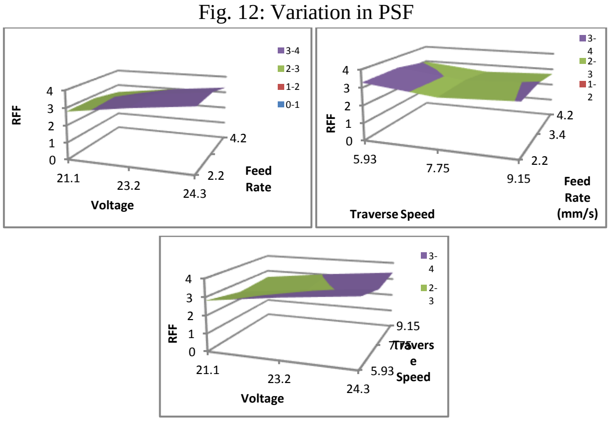

Fig. 13: Variation in RFF

As with increase in voltage the bead becomes flatter, i.e., bead width increases but reinforcement height and penetration decrease therefore both RFF & PSF increase. With increase in traverse speed, both factors should follow a trend similar to be bead width and inverse to bead height and penetration respectively. But, Form Factor follows a trend similar to Bead height despite the fact that bead height is inversely proportional to RFF. It is due to the presence of bead width as a factor. RFF decreases initially because bead width decreases but after a certain value bead height decreases at a higher rate therefore form factor starts increasing. With increase in feed rate all the parameters including bead width, bead height and penetration increase but bead width increase at a higher rate, therefore both RFF & PSF increase initially but when feed rate reach a higher value, but start decreasing.

4) HRB

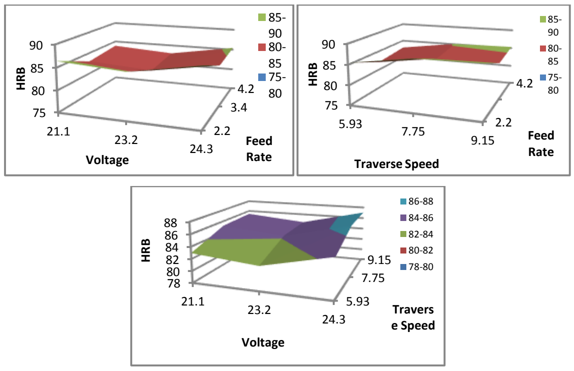

Fig. 14: Variation in HRB

Hardness of the weld zone firstly decreases slightly with increase in voltage and then increases continuously. It increases with traverse speed and then remains constant.

5) Bead Height (H)

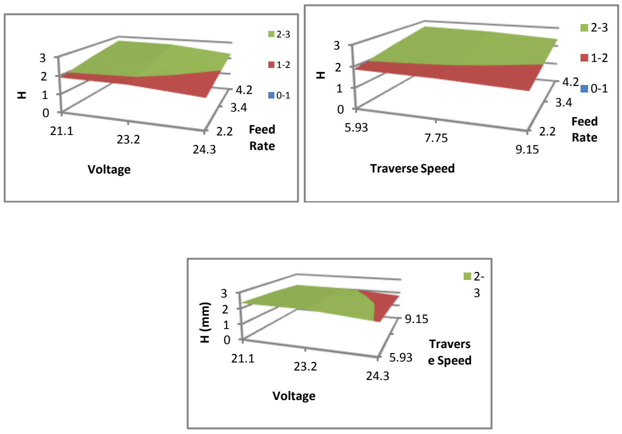

Fig. 11: Variation in Bead Height

Bead Height decreases with increase in Voltage and Traverse speed while it increases with increase in Feed Rate.

This is consistent with the fact that on increasing the voltage the weld beads become more flatter, which in turn decreases the bead height. The reason for decrease in reinforcement height has been discussed in previous paragraph. As with increase in feed rate more amount of metal is deposited therefore bead height increases.

5.2 Conclusions

It has been observed that the wire feed rate has the maximum effect on output parameters in most cases as it has been ranked 1 for most of the output parameters. Also based on the

Grey Relational Methodology, experiment number 3 is considered to be the most optimum combination of process parameters. The observation set is as follows: Experiment Number 3 has the highest value of current and the largest wire feed rate, therefore, it results in higher penetration and reinforcement height and also fine welds are formed more commonly. As with increase in Voltage, Penetration Shape factor and Reinforcement form factor also increases therefore, lower value of Voltage is preferred to have more penetration and reinforcement height making the weld stronger.

Table 20: Order for grey based Taguchi method

Order	Exp. No.	Current (Amp)	Voltage (Volts)	Feed Rate (mm/s)	Traverse Speed (mm/s)
1	3	159	21.1	4.2	9.15
2	9	159	24.3	4.2	7.75
3	7	89	24.3	2.2	9.15
4	6	159	23.2	4.2	5.93
5	2	137	21.1	3.4	7.75
6	1	89	21.1	2.2	5.93
7	5	137	23.2	3.4	7.75
8	4	89	23.2	2.2	7.75
9	8	137	24.3	3.4	5.93

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