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Optimization of MIG welding process parameter for minimizing heat affected zone

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Abstract-The present work is intended to optimize the existing MIG welding process parameters utilized by an industrial firm, which engaged in fabrication of generator set. The optimized process parameter will improve overall weld quality by achieving minimum heat affected zone (HAZ) on canopy of generator set. Design of experiment based on Box Behnken Design of Response Surface Methodology was developed in Design expert software, which was used for analysis of results.

Keywords-Box Behken Design, Heat affect zone (HAZ), Response Surface Methodology and Metal Inert gas welding.

1. INTRODUCTION

The present situation of manufacturing industries is to make the profits by producing best quality of products with high accuracy. To join metals permanently, welding is process which considered as an high efficient and economical and is widely used by industries. Out of many welding processes, MIG welding is adopted for joining steels, aluminum and non-ferrous materials at a much faster pace and it also fulfills the quality characteristics. Optimization of welding parameters is thus necessary for obtaining good quality of weld joints. Many optimization techniques can be used for the desired output responses. Designs of experiment fulfill the need for generating model for conducting experimental runs. Several mathematical models can establish the relation between the input and output responses. The use of various design of experiments with optimization techniques proved to be effective for achieving the objective function.

2. LITERATURE REVIEW

Sloderbach and Pająk **[1]** presented an possible procedure to predict the heat affected zone, its segments and these zones for welding of carbon steels. The calculations are limited to the maximum time of 3 minutes. Taking everything into account, it ought to be included that on account of materials (steel) intended to work at raised temperatures; one shall restrict crushing of grains because of welding. Such a structure emerges in the HAZ and decreases the creep strength of welded components, in light of the fact that countless grain limits improve diffusion process. Bamankar et al. **[2]** reviewed how Welding procedure parameters are influencing quality and efficiency of welding. Optimization techniques are used to improve the procedure parameters. This review depends on enhancement strategies and investigation tools utilized by researchers to enhance the parameters. Also many researcher proceeded research on various response parameters like bead height, bead width, depth of penetration, micro-hardness, micro-structural study etc. Ghosh et al. **[3]** studied and evaluate the submerged curve welding (SAW) technique for better quality and high deposition rate which is utilized to join plates of higher thickness in burden bearing segments. This procedure of circular segment welding gives a cleaner high volume weldment. A typical issue in the utilization of SAW procedure is about the heat influenced zone in and around the weldment. An endeavor has been made in this paper to survey the HAZ of submerged circular segment welding of auxiliary steel plates through the investigation of the grain structure by methods for advanced picture processing procedures. Butola et al. **[4]** detail study is carried out to observe the effect of welding parameter on hardness of 304L Stainless steel by using both spray and pulse MIG welding. Experiments were carried out taking 20mm constant gap between work piece and welding nozzle using the mixture of CO_2 and Ar as shielding gas at different flow rates, where plate thickness, gas flow rate and travel speed are considered as process parameter. The maximum value of hardness was observed in HAZ, results in conclusion that grain size are finest in HAZ and microhardness value increases from base metal to HAZ. Yadav et al. **[5]** observed that for increment in voltage there is increment in Penetration and there is slight increment in HAZ hardness as for increment in Current. So it might be reasoned that utilizing higher voltage of 24v, better penetration can be acquired. Additionally the ameliorated penetration has compelled to perform rest of numerous pass welding with 24 v and 130amp current. o 24v and 130amp current is recommended for welding the examples. Ambekar and Wadhokar **[6]** studied the effects of welding process parameters on weld penetration of Stainless Steel AISI 410 in Gas Metal Arc welding. The input process parameters selected were, welding speed, current, wire diameter and ANOVA method was used for obtaining percentage contribution. Mishra et. al. **[7]** determined the effect of welding variables such as heat input which was controlled by welding current, speed and voltage on mechanical properties of low carbon steel of grade EN-3A in gas metal arc welding process. After observation of results, it is found that tensile strength increases with increasing heat input but there were no significant effect of shielding gas been found. Vagh and Pandya **[8]** carried out friction stir welding on AA-2014 T6 Aluminium Alloy to find out the effects of process parameters on mechanical strength of welded joints using Taguchi orthogonal DOE technique and found out the highest strength is obtained at Tool Design-II,1400 rpm tool rotation speed and 20mm/min tool travel speed. Highest elongation obtained at Tool Design-II. 1000 rpm tool rotation speed & 20mm/min tool travel speed and ANOVA gives the tool design as the main input parameter and is most contributing factor having statistical influence on Tensile Strength (74.01%) and nugget hardness (86.74%). Chavan et al. **[9**] studied the effects of heat input and welding speed on distortion of material by MIG welding, experimental and results shown and predicted the distortion, shrinkages of weld joint numerically. This is economical process for a welding firm. By simulating the process, it is also concluded that heat input, welding speed are high significant factor for the weld response. Kocher et al. **[10]** work was done by taking speed as variable while keeping voltage, current, feed rate and distance between (nozzle tip and work piece) constant in this experiment. The effect of weld speed on the weld bead profile discussed with the effect of weld speed on the fusion angle and wetting angle. The effect of weld speed on weld bead dilution. i.e penetration area and reinforcement area were also discussed.

3. EXPERIMENTAL SETUP

Experimental setup is an important step for any experimental research. It plays a vital role in the completion of the research. In this study, MIG welding machine is used to perform the experiments. The Power Compact 255 MIG welding machine has been used for the experimentation in the industry with shielded gas taken as 100% CO2.

3.1 WORK MATERIAL & FILLER WIRE

Commercial mild steel IS 513-2008, thickness ranging 50x50x1.5mm is selected for experimentation.

Table 3.1 Composition of IS 513-2008 CR2 Steel

Steel		C %	Mn %	S%	P%	Al %	Si %
IS 513-2008 grade A	Min	.035	.15	-	-	.02	-
	Max	.070	.40	.02	.025		0.4

Welding wire used for the purpose of fabrication of mild steel is ER70S-3. The composition for the welding wire is given in the table further:

Table 3.2 Composition of ER70S-3 welding wire (as obtained from the industry)

Welding wire	C%	Mn%	S%	P%	Si%
ER70 S-3	0.15	1.4	0.035	0.025	0.45

3.2 DESIGN OF EXPERIMENT

In present work, RSM is used to design the experiments for MIG welding with the help of Box Behnken design method in Design Expert-10 software. Welding voltage, current and gas flow rate are taken as input process parameters and three levels for each parameter has been selected according to the pilot experiments.

After selecting the input process parameters and their levels, the experimental run order is generated by using Response surface methodology with the help of

BBD (Box Behnken design) for MIG welding, which has given 20 experiment runs and experiments conducted according to the run order produced by the RSM.

Table 3.3 Design of Experiment

		Factor 1	Factor 2	Factor 3
Std	Run	A:Current	B:Voltage	C:Gas flow rate
		Ampere	Volt	liter/min
6	1	110	27	11
19	2	95	27	13
7	3	80	27	15
3	4	80	30	13
8	5	110	27	15
10	6	95	30	11
14	7	95	27	13
5	8	80	27	11

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12	9	95	30	15
15	10	95	27	13
4	11	110	30	13
1	12	80	24	13
18	13	95	27	13
20	14	95	27	13
11	15	95	24	15
16	16	95	27	13
13	17	95	27	13
2	18	110	24	13
9	19	95	24	11
17	20	95	27	13

Table 3.4 Experimentation Results

4. RESULTS AND DISCUSSIONS

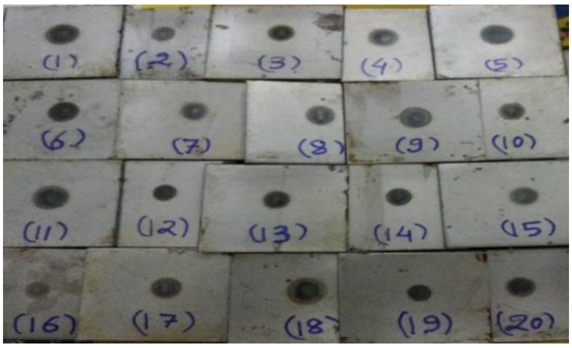
Experiments were conducted by taking the range of input parameter based on literature and the available range on MIG welding equipment in the factory. The diameter HAZ was considered as response parameter. The experiments carried out on the basis of Box Behnken Design (BBD) approach and the results are shown in Table 4.2 After we obtained the welded specimen, HAZ of each specimen is measured with the help of Vernier caliper vision system, and which was main output response to minimize.

		Factor 1	Factor 2	Factor 3	Response 1
Std	Run	A:Current	B:Voltage	C:Gas flow rate	Dia
		Ampere	Volt	liter/min	mm
6	1	110	27	11	10
19	2	95	27	13	5.8
7	3	80	27	15	6.4
3	4	80	30	13	7.5
8	5	110	27	15	10
10	6	95	30	11	7
14	7	95	27	13	6.2
5	8	80	27	11	6.4
12	9	95	30	15	7
15	10	95	27	13	6.2
4	11	110	30	13	10.4
1	12	80	24	13	5.5
18	13	95	27	13	5.8
20	14	95	27	13	5.8
11	15	95	24	15	5.8
16	16	95	27	13	5.2
13	17	95	27	13	5.8
2	18	110	24	13	10
9	19	95	24	11	5.2
17	20	95	27	13	6.2

Table 4.1 Range of input and output parameter

Name	Goal	Lower Limit	Upper Limit
A:Current	is in range	80	110
B:Voltage	is in range	24	30
C:Gas flow rate	is in range	10	15
Diameter	Minimize	5.2	10.4

Figure 4.1 MIG welded sample



The results obtained by using RSM approach are shown in table 4. 2

Table 4.2 Results by using Response surface methodology (RSM)

	CURRENT (A)	VOLTAGE (V)	GAS FLOW RATE (L/MIN)	DIAMETER (MM)	DESIRABILITY
1	88.175	25.882	11.815	5.182	1.000
2	87.043	24.055	14.628	5.167	1.000
3	89.074	24.333	10.827	4.873	1.000
4	86.519	24.630	11.494	4.920	1.000
5	91.111	24.852	11.191	5.055	1.000
6	87.570	24.509	14.330	5.152	1.000
7	89.790	25.284	13.407	5.166	1.000
8	86.778	24.756	12.778	4.998	1.000
9	89.000	24.800	11.389	4.952	1.000
10	88.148	24.363	13.047	4.957	1.000
11	87.644	24.983	14.071	5.172	1.000
12	82.333	24.200	12.611	5.157	1.000
13	87.864	24.246	14.312	5.122	1.000
14	86.658	24.424	14.124	5.117	1.000
15	82.512	24.377	10.943	5.115	1.000
16	86.231	24.716	12.410	4.978	1.000
17	87.098	24.368	14.531	5.177	1.000
18	92.100	25.228	12.038	5.199	1.000
19	**88.310**	**24.152**	**11.357**	**4.825**	**1.000**
20	88.048	24.493	12.105	4.902	1.000
21	82.772	24.597	12.543	5.185	1.000
22	92.229	24.039	10.335	5.033	1.000
23	84.708	24.012	14.170	5.149	1.000
24	89.023	25.452	12.379	5.102	1.000
25	87.008	24.764	10.108	4.980	1.000
26	87.755	25.402	10.971	5.080	1.000

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27	91.266	25.368	11.300	5.162	1.000
28	90.505	24.115	11.255	4.899	1.000
29	84.134	24.611	10.132	5.065	1.000
30	85.945	24.168	10.776	4.847	1.000
31	89.568	25.718	10.865	5.182	1.000
32	89.422	25.467	13.464	5.191	1.000
33	86.773	25.348	11.267	5.075	1.000
34	88.452	24.365	14.377	5.152	1.000
35	85.755	25.107	13.590	5.173	1.000
36	91.914	24.165	11.012	5.008	1.000
37	89.036	24.325	14.469	5.178	1.000
38	92.547	24.676	10.011	5.185	1.000
39	86.012	25.026	12.318	5.042	1.000
40	91.085	24.383	13.786	5.168	1.000
41	91.672	24.066	13.818	5.193	1.000
42	88.799	24.217	10.381	4.857	1.000
43	87.848	24.590	12.629	4.949	1.000
44	87.704	24.998	10.981	4.985	1.000
45	85.784	24.272	13.728	5.061	1.000
46	90.893	24.986	10.393	5.095	1.000
47	89.099	25.597	10.762	5.146	1.000
48	89.184	25.324	11.251	5.065	1.000
49	90.256	25.076	11.075	5.052	1.000
50	87.079	24.590	14.447	5.186	1.000
51	91.698	24.303	11.566	5.014	1.000
52	86.086	24.393	14.278	5.154	1.000
53	89.478	24.854	11.643	4.977	1.000
54	88.894	24.024	12.727	4.897	1.000
55	89.545	25.253	13.168	5.130	1.000
56	88.776	25.120	11.462	5.011	1.000
57	88.418	24.695	11.744	4.927	1.000
58	84.649	24.239	13.017	5.018	1.000
59	92.526	24.821	10.389	5.186	1.000
60	88.438	25.581	11.608	5.110	1.000
61	89.837	25.231	13.023	5.123	1.000
62	84.771	24.847	13.073	5.121	1.000
63	84.534	24.307	14.094	5.182	1.000
64	86.489	25.574	11.506	5.136	1.000
65	90.559	24.501	11.768	4.969	1.000
66	86.770	24.077	13.289	4.952	1.000
67	89.551	24.971	12.452	5.029	1.000
68	91.227	25.193	12.910	5.177	1.000
69	87.319	25.107	11.208	5.008	1.000
70	85.452	24.482	10.583	4.936	1.000
71	87.747	24.237	12.363	4.876	1.000
72	89.157	24.196	12.964	4.949	1.000
73	91.407	24.957	10.749	5.105	1.000
74	84.534	24.986	12.861	5.145	1.000
75	87.010	25.018	11.603	4.992	1.000
76	87.678	24.268	13.076	4.945	1.000

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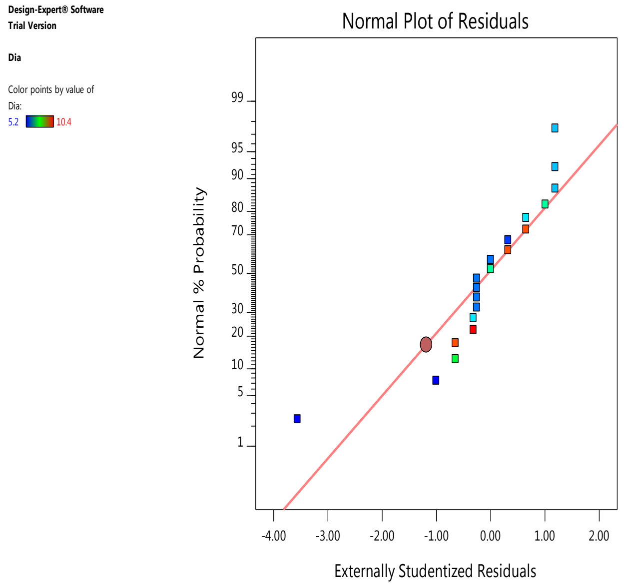
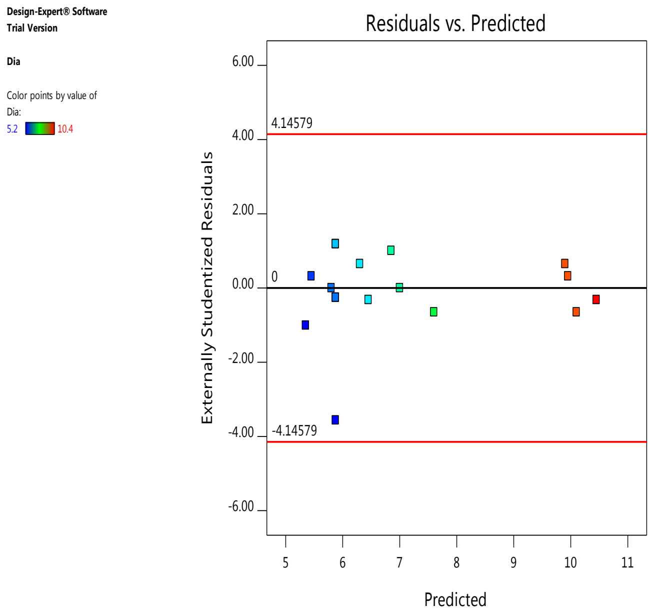
77	89.281	25.598	11.973	5.126	1.000
78	88.914	25.382	10.481	5.106	1.000
79	86.734	25.813	11.782	5.188	1.000
80	87.556	24.602	14.064	5.119	1.000
81	84.553	24.604	11.626	5.002	1.000
82	90.764	24.980	10.441	5.083	1.000
83	86.016	25.072	12.679	5.072	1.000
84	86.822	24.473	11.453	4.883	1.000
85	84.885	24.177	10.223	4.911	1.000
86	86.935	25.539	12.600	5.137	1.000
87	82.710	24.080	10.736	5.032	1.000
88	92.656	24.175	12.978	5.180	1.000
89	88.658	25.303	10.669	5.072	1.000
90	87.539	25.144	13.733	5.151	1.000
91	89.274	25.098	12.491	5.045	1.000
92	84.040	24.604	13.283	5.147	1.000
93	86.695	24.955	11.501	4.984	1.000
94	91.120	25.269	12.031	5.137	1.000
95	91.151	25.395	11.886	5.160	1.000
96	88.921	24.870	11.677	4.966	1.000
97	89.815	24.536	10.689	4.939	1.000
98	88.564	24.487	13.762	5.067	1.000
99	87.919	24.561	14.110	5.122	1.000
100	84.734	24.491	13.435	5.101	1.000

4.1 INDIVIDUAL PLOTS OF EFFECT OF PROCESS PARAMETERS ON DIAMETER





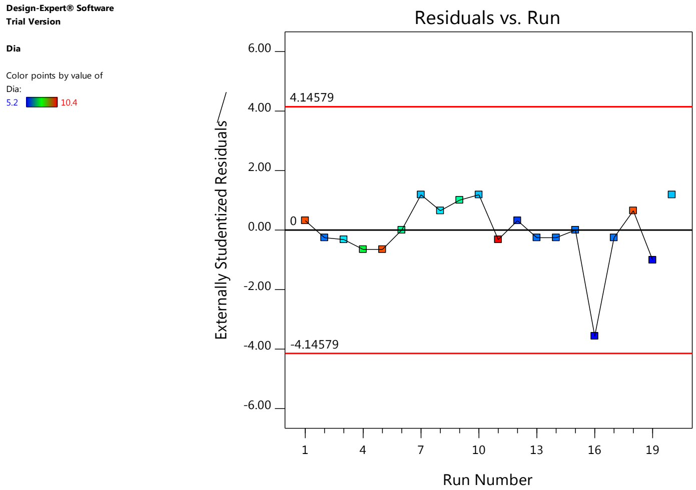
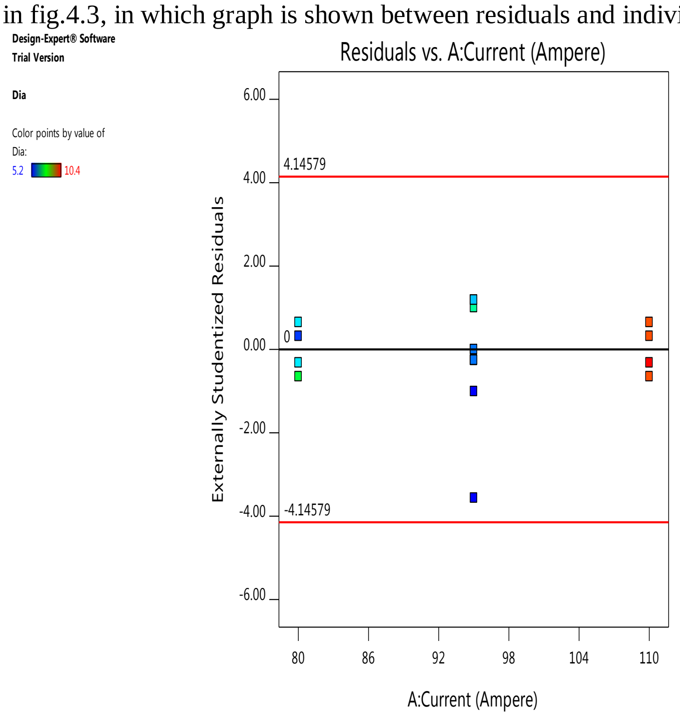
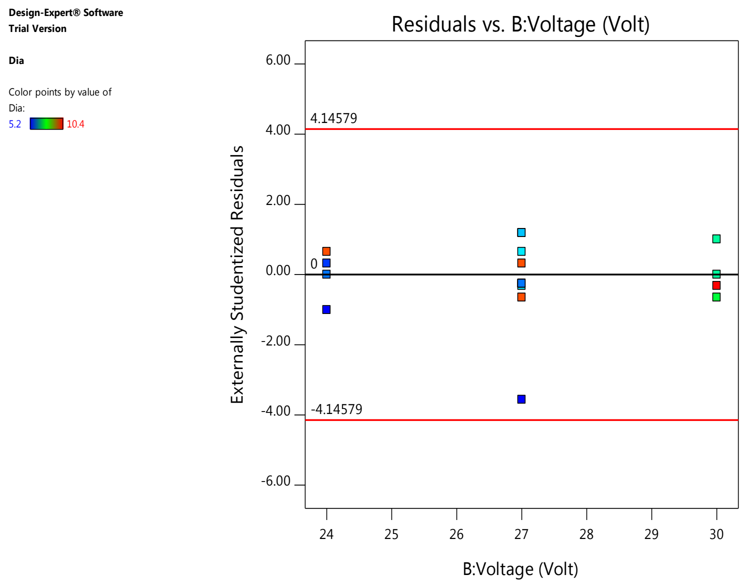


Figure 4.2 a)Normal plot of residuals (b) Predicted vs actual (c) Residual vs Run

Plot between current, voltage and gas flow rate vs Residuals

The diagnostic plot is drawn in fig.4.3, in which graph is shown between residuals and individual input parameter.





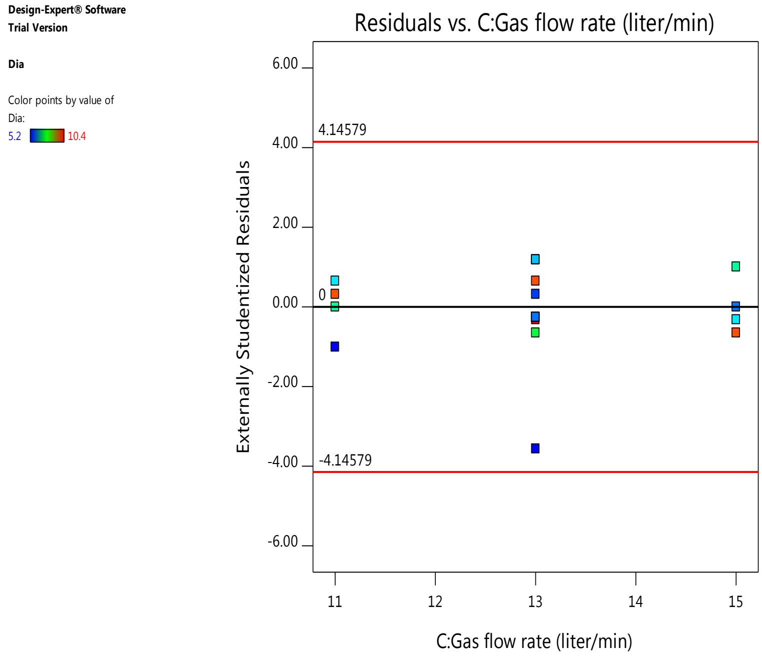
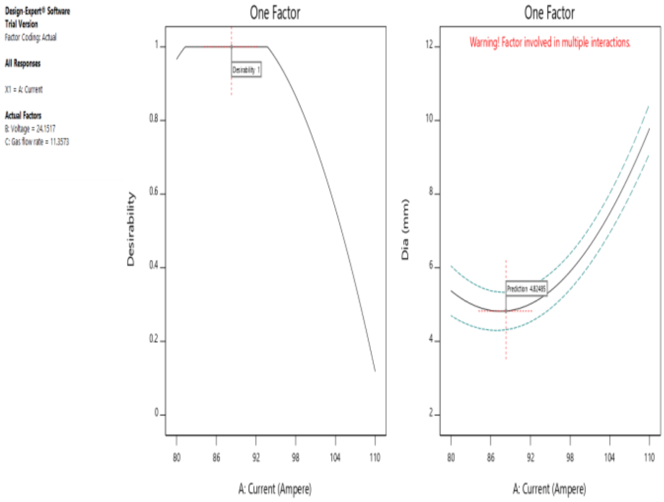


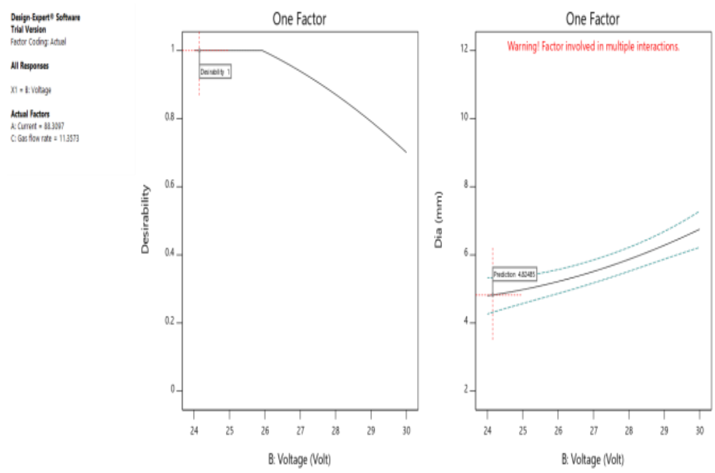
Figure 4.3 a) Residuals vs Current (b) Residual vs voltage (c) Residual vs Gas flow rate

Individual Plots

Plots shown in figure 4.4 which is showing individual effect of different input parameter on diameter of heat affected zone. When both current and voltage increases from specific limit, it is observed that diameter increases sharply, however in case of gas flow rate no marginal effect is seen as shown below



(a)



(b)

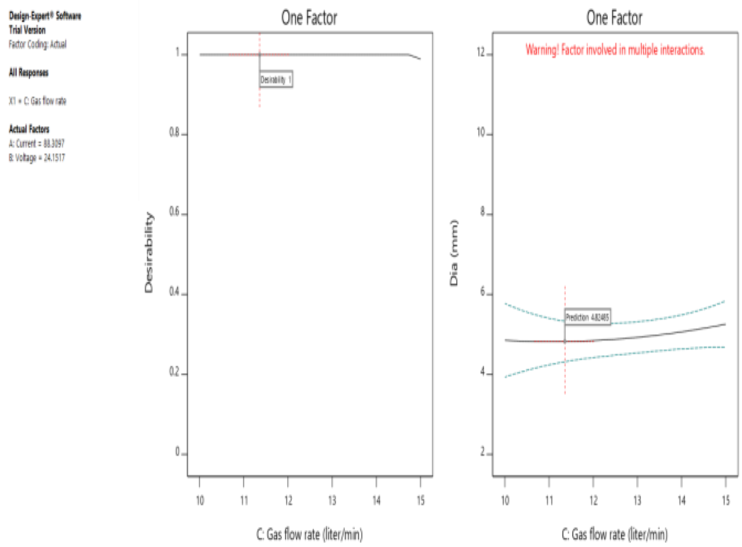
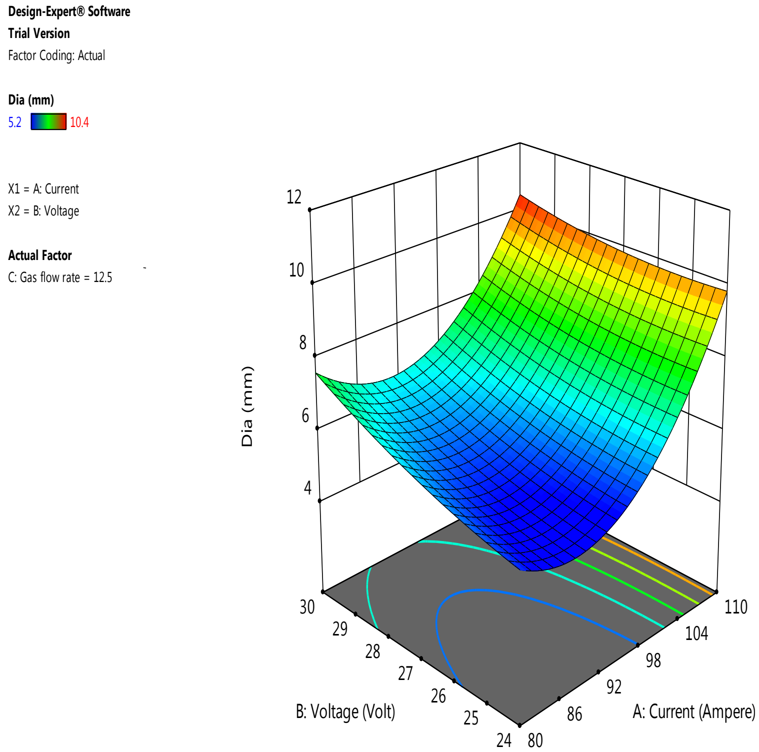


Figure 4.4 a) Current vs Diameter (b) Voltage vs Diameter (c) Gas flow rate vs Diameter

4.4 SURFACE PLOT BETWEEN TWO PARAMETERS FOR DIAMETER.



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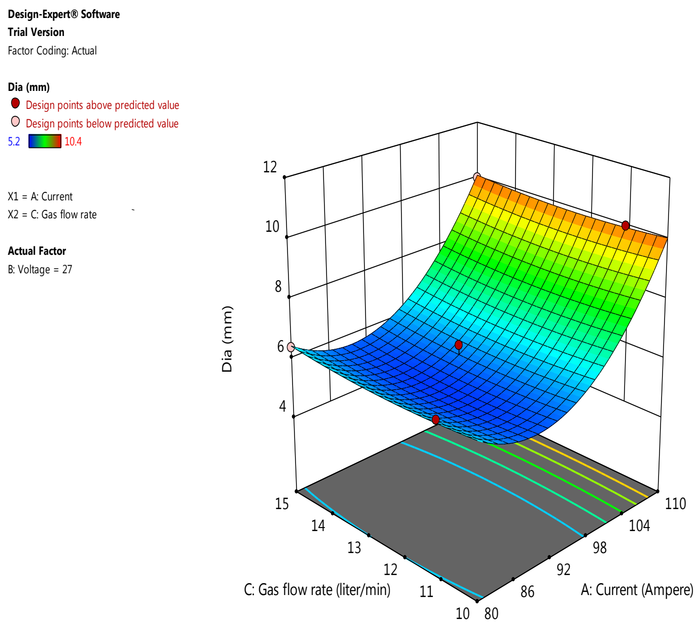

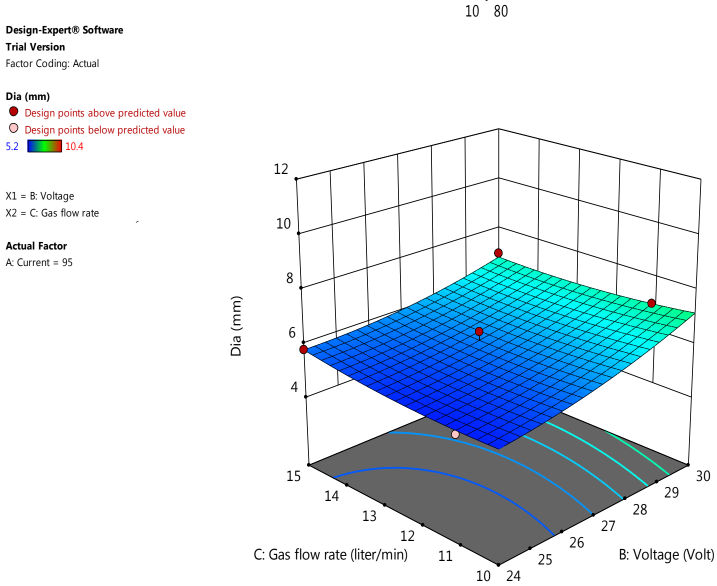

Fig.4.5 Surface plot between Diameter vs Gas flow rate and Voltage in a,b &c

Desirability Ramp plots for optimization

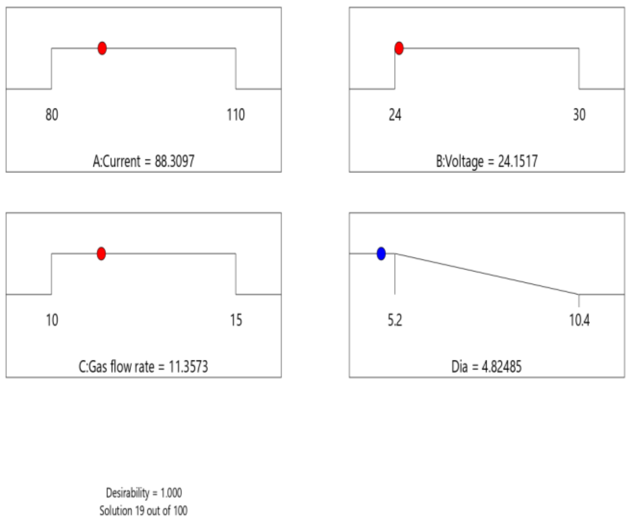

Fig.4.6 Predicted desirability results by ramp plot Desirability, Bar Plot for Optimization

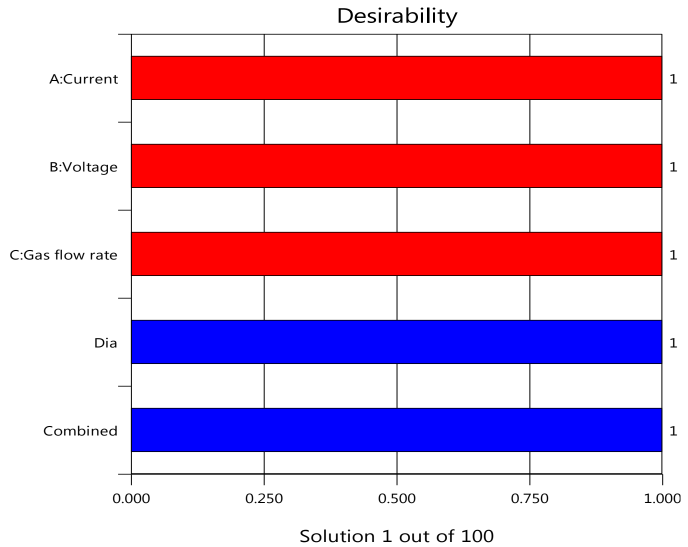

Fig.4.7 Desirability bar plot for optimization

5. VALIDATION

The optimum parameters of MIG welding obtained were validated experimentally. However, the optimum parameter as obtained from analysis could not be set on MIG welding machine, the nearest possible value of optimal parameters were used for experimentation given in table 5.1.

Table 5.1 Optimum values of parameter

Parameter	Optimum value	Value used for experimentation
Current (A)	88.31	88
Voltage (V)	24.15	24
Gas flow rate (litre/Min)	11.36	11

The values obtained after experimentation were compared with the predicted values and are given in table 5.2.

Table 5.2 Validation of results

Response	Experimental value(mm)	Predicted value(mm)	Error %
Diameter	5.04	4.825	4

It is observed that experimental response is approximately same as that obtained from the optimized value. Thus, regression model obtained from analysis may be considered accurate as the percentage error of the output response is less than 5%.

5.1 CONCLUSIONS

The optimum parameters were obtained for a good quality weld having minimum heat affected area. The following conclusions are drawn on the basis of experimental work and analysis of the results:

1. The most dominant parameter of MIG welding affecting the weld quality was found to be welding current, followed by voltage and gas flow rate.
2. Optimization of MIG welding process parameters was carried out for achieving optimum results. The optimum values for current, voltage and gas flow rate were found to be 88A, 24V and 11 litre/min respectively.
3. Experimental validation of the results was carried out and the percentage error for Minimum HAZ found to be 4% which was within the permissible limit.

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