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Optimization of MIG Welding Process Parameters for AISI-4340 (34CrNiMo6) Steel Test Specimen Using Composite Desirability Function

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ABSTRACT

MIG welding process is one the most used welding technique for industries especially when other techniques are not feasible. The present research work help the scientific research community to find the effect of the process parameters of MIG welding on cylindrical object of the test materials. This type of research work is contributing effective part when any one goes for welding on cylindrical object. Another advantage of the research work was to show the importance of the design of experiment methods like Taguchi method, Regression modelling, ANOVA analysis, Multi Objective Optimization. The purpose of the present investigation is to optimize the process parameters of the MIG welding for AISI-4340 (34CrNiMo6) steel object. The reason to select the MIG welding research area is the small scale industries and road side shops where MIG is widely used for joining the materials. There was various operational drawbacks during performing the operation, so present investigation help the welder who use MIG machine for joining the high grade steel. The aim of the present investigation is to optimize the MIG welding process parameters for AISI-4340 steel object using CD function multi objective optimization for two response parameters welding time and micro hardness. Taguchi method is selected for generated experiments for present investigation.

I. INTRODUCTION

Joining is the one the common and important part for the assembly products for most of the industries. Joining became crucial when leakage was one common issue in industries. Various joining techniques available in market like riveted joints, bolted joints, welding joints and many more [1-2]. Welding joints was considered as most common and better techniques for assembly products where leakage was one of the common issues [3-4]. Welding joining method has various advantages over other techniques like permanent joint among base objects which increase durability for long time spam, joint was free from corrosion defects, seasonal defects and other strength related issues [5-6].

Welding process was classified into two separations which are called as Plastic welding process and Fusion welding process. In plastic welding process (High Pressure welding), pressure and temperature was created on the base objects and then joining operation was performed [7]. In fusion welding process extensive heat was generated near the welding area of the base metals and joining was performed [8]. In general contrast, four types of welding process was used for joining the metals objects which are MIG welding, TIG welding, shielded metal arc welding and flux-cored arc welding [9-11]. The present investigation was on the application of MIG welding techniques to find the effect of the process parameters on the selective response parameters. The four types of welding methods were shown in figure 1.

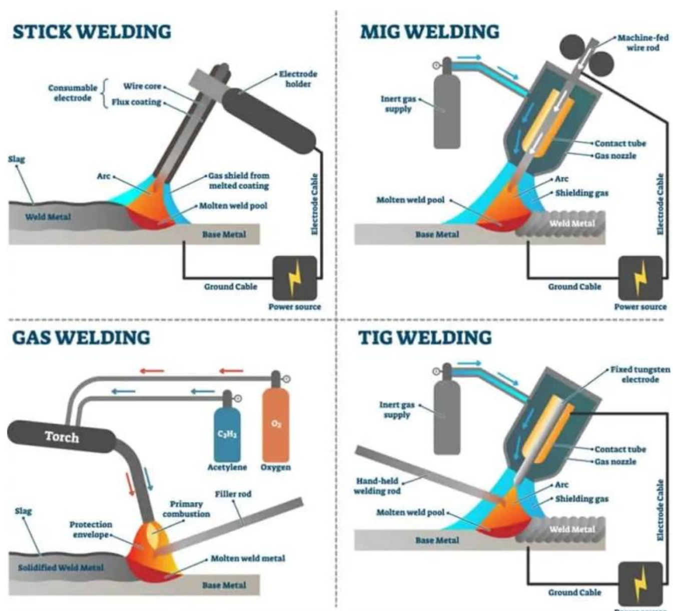

Figure 1. Welding methods (source: https://toolshaven.com)

II. EXPERIMENTAL METHODOLOGY

Flowchart of the presented experimental methodology is shown in the figure 2.

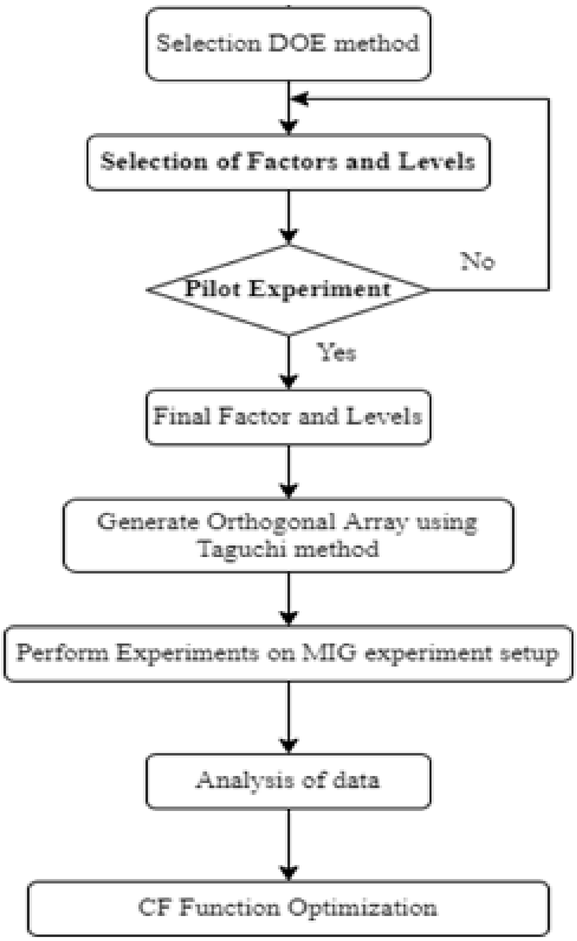

Figure 2. Flowchart of the presented experimental methodology

A. *MIG Machine Technical Specification*

The machine selected for present investigation is shown in figure 3. The machine used present study has facility to change the voltage and current facility for better welding options. The options have available in machine.

Figure 3. MIG Machine

B. *Factor and Levels*

In present investigation three input parameters are selected for investigation which are gas flow rate, gap among work pieces and feed rate of filler materials wire. The selections of the levels are conduct using pilot experiments which was shown in figure 2. The final factors and levels for present investigation are representing in table 1.

Table 1. Factors and levels for MIG work

Factors/Levels	Feed Rate (Inch/sec)	Gas Flow Rate (PSI)	Distance (mm)
I	3	2.0	0.0
II	4	2.5	0.2
III	5	3.0	0.4
IV	6	3.5	0.6

These factors and levels are required to select the experiment table for present investigation. The selection of experiment runs are done by using Taguchi method and the final orthogonal array is presented in table 2. The distance calculation is done by using vernier caliber device. To select this as input parameter is to find the strength of welded joint when base metals are not in contact with each other. In present investigation two response parameters welding time and Micro hardness are selected. Welding time was measured by using stop watch and micro hardness was measured by hardness tester machine.

Table 2. Orthogonal array developed for present experiment work

Run	FR	GFR	Distance	Run	FR	GFR	Distance
1	3	2	0	9	5	2	0.4
2	3	2.5	0.2	10	5	2.5	0.6
3	3	3	0.4	11	5	3	0
4	3	3.5	0.6	12	5	3.5	0.2
5	4	2	0.2	13	6	2	0.6
6	4	2.5	0	14	6	2.5	0.4
7	4	3	0.6	15	6	3	0.2
8	4	3.5	0.4	16	6	3.5	0

C. Test Specimen and Dimensions

The material select for present study is AISI-4340, the reason to select the material for present investigation is its high application for industrial purpose. The raw work pieces are shown in figure 4. Welded joint required to make by MIG welding machine is shown in figure 5 in which proper welding design has shown.

Figure 4. AISI-4340 work piece material

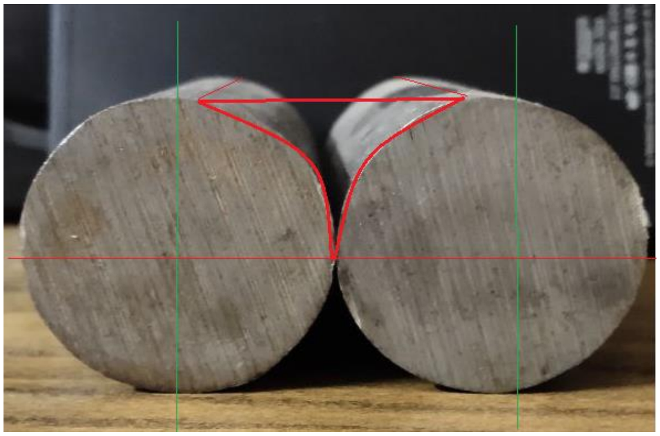

Figure 5. Welding bead required to make for present investigation

The length of the work piece was 70 mm and diameter was 30 mm. Bead was made from center point matching for both cylindrical objects.

Data Recording

As seen in table 2 total 16 experiments are required to run on MIG machine with desired boundary conditions. The data has recorded for welding time and micro hardness and present in table 3.

Table 3. Final response table for present investigation

Run	FR	GFR	Distance	Welding Time	Micro Hardness	Run	FR	GFR	Distance	Welding Time	Micro Hardness

1	3	2	0	56.24	515	9	5	2	0.4	51.56	469
2	3	2.5	0.2	53.68	517	10	5	2.5	0.6	58.94	523
3	3	3	0.4	53.62	489	11	5	3	0	49.37	519
4	3	3.5	0.6	62.51	428	12	5	3.5	0.2	55.86	562
5	4	2	0.2	52.37	460	13	6	2	0.6	59.36	541
6	4	2.5	0	54.61	507	14	6	2.5	0.4	56.81	483
7	4	3	0.6	61.82	491	15	6	3	0.2	52.28	491
8	4	3.5	0.4	60.37	532	16	6	3.5	0	45.88	553

III.

IV. Result and Discussion

In this present investigation analysis is divided into two major sections which are following: in fist section signal to noise ratio analysis and optimal solutions are discussed but in second section regression modeling and optimization is performed.

Signal to Noise Ratio Calculation for Welding Time and Micro Hardness

For welding time calculation smaller is better option has selected for signal to noise ratio analysis. The first step was to calculate the individual S/N ratio then by using this S/N ratio values delta parameter was calculated, which help to find the rank among input parameters. The final S/N ratio table for welding time is present in table 4 and for micro hardness the final S/N ratio results are present in table 5.

Table 4. S/N ratio analysis for welding time

Level	FR	GFR	Distance
1	-35.03	-34.77	-34.21
2	-35.14	-34.96	-34.57
3	-34.62	-34.66	-34.88
4	-34.54	-34.93	-35.65
Delta	0.6	0.3	1.44
Rank	2	3	1

Table 5. S/N ratio analysis for micro hardness

Level	FR	GFR	Distance
1	55.36	55.5	55.89
2	55.52	55.67	55.65
3	55.81	55.52	55.46
4	55.8	55.8	55.48
Delta	0.45	0.3	0.44
Rank	1	3	2

As seen in tale 4, the crucial parameter for welding time is distance among test specimen and least crucial parameter is gas flow rate. For Micro hardness the crucial parameter is feed rate and least crucial parameter is gas low rate. The same analysis for both response parameters are present in figure 6 and figure 7.

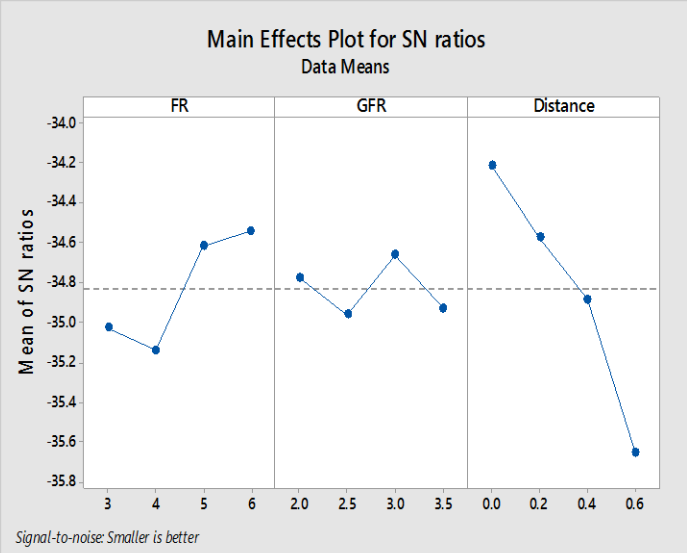

Figure 6. S/N ratio analysis for welding time

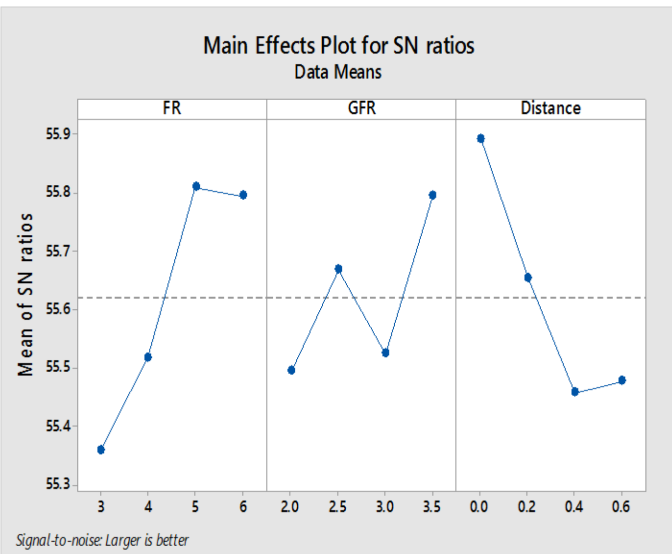

Figure 7. S/N ratio analysis for welding time

As seen in figure 6, the best optimal solution for welding time is, 6 inch/sec feed rate, 3.0 PSI for gas flow rate, and zero mm gap among two object work piece. As seen in figure 7, the best optimal solution for welding time is, 5 inch/sec feed rate, 3.5 PSI for gas flow rate, and zero mm gap among two object work piece.

Regression Equations for Welding Time and Micro Hardness

In this section regression modeling was adopt for both response parameters. The selection of right modeling equation is quite experience and for present investigation linear and interaction model has adopted and the final equations with

Welding Time = 63.7 - 2.02 FR + 0.55 GFR - 99.5 Distance - 0.401 FR*GFR + 12.56 FR*Distance+ 20.64 GFR*Distance

Table 6. ANOVA analysis for welding time

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	6	297.08	49.5133	24.99	0
Linear	3	99.578	33.1926	16.75	0.001
FR	**1**	**2.906**	**2.9055**	**1.47**	**0.257**
GFR	1	42.929	42.9286	21.67	0.001
Distance	1	53.744	53.7437	27.13	0.001
2-Way Interaction	3	93.388	31.1292	15.71	0.001
FR*GFR	**1**	**0.355**	**0.3546**	**0.18**	**0.682**
FR*Distance	1	55.55	55.5496	28.04	0
GFR*Distance	1	37.483	37.4833	18.92	0.002
Error	9	17.831	1.9812		
Total	15	314.911			

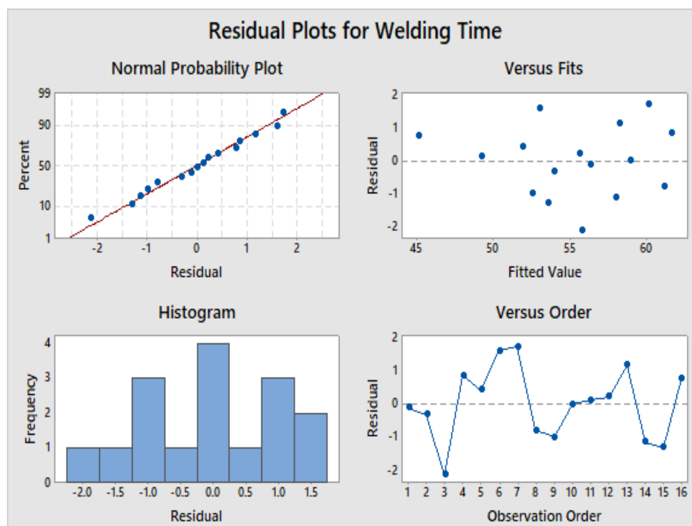

Figure 8. Residual plot for welding time

Table 7. Model summary for welding time

S	R-sq	R-sq(adj)	R-sq(pred)
1.40757	94.34%	90.56%	80.17%

Hardness = 745.6 - 111.7 FR + 36.6 GFR - 56 Distance + 21.14 FR*GFR + 148.3 FR*Distance - 222.7 GFR*Distance

Table 8. ANOVA analysis of micro hardness

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	6	18071.8	3011.97	41.31	0.000
Linear	3	7986.4	2662.15	36.51	0.000
FR	1	576.0	576.01	7.90	0.020
GFR	1	7410.0	7410.02	101.63	0.000
Distance	1	0.4	0.40	0.01	0.943
2-Way Interaction	3	13089.3	4363.11	59.84	0.000
FR*GFR	1	982.8	982.84	13.48	0.005
FR*Distance	1	7741.0	7741.02	106.17	0.000
GFR*Distance	1	4365.5	4365.45	59.88	0.000
Error	9	656.2	72.91		
Total	15	18728.0			

Table 9. Model Summary for micro hardness

S	**R-sq**	**R-sq(adj)**	**R-sq(pred)**
8.53868	96.50%	94.16%	88.41%

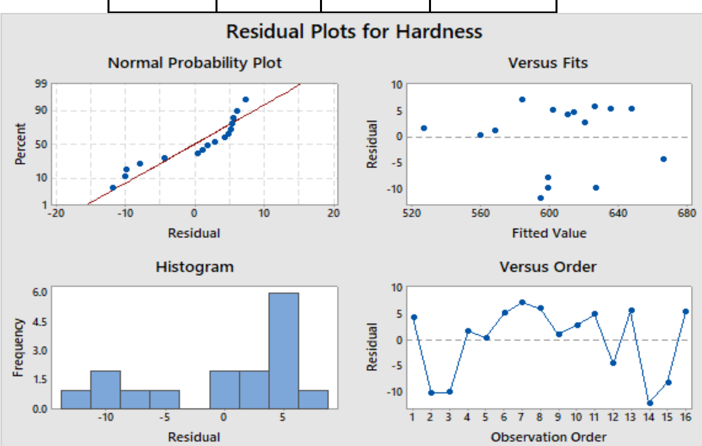

Figure 9. Residual plot for micro hardness

CD Function optimization

In the table 10 and 11 shown the goals criteria of CD function optimization and the final solution for MIG welding process.

Table 10. Goals criteria for CD function optimization

Response	**Goal**	**Lower**	**Target**	**Upper**	**Weight**	**Importance**
Welding Time	Minimum		45.88	62.51	1	1
Hardness	Maximum	528	662.00		1	1

Table 11. Final solution for MIG welding process

Solution	**FR**	**GFR**	**Distance**	**Welding Time Fit**	**Hardness Fit**	**Composite Desirability**
1	5.63636	3.5	0	46.3515	661.316	0.983204

V. CONCLUSION

MIG welding process is one the most used welding technique for industries specially when other techniques are not feasible. The present research work help the scientific research community to find the effect of the process parameters of MIG welding on cylindrical object of the test materials. This type of research work contributes effective part when any one goes for welding on cylindrical object. Another advantage of the research work has to show the importance of the design of experiment methods like Taguchi method, Regression modeling, ANOVA analysis, Multi Objective Optimization. The conclusion of the work is that the effect of process parameters on the response parameters are crucial for some parameters like welding speed and welding gas pressure are more crucial than other process parameters. Optimal cases are also found by using CD function methodology.

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