Optimization of bead Geometry in Austenitic Stainless Steel Cladding using Taguchi's Method and Multi Objective Genetic Algorithm

P. Surendran, B. Senthilkumar, and T. Kannan.

Abstract----**This paper presents the effect of welding parameters on bead geometry in multipass gas metal arc welding (GMAW) process. Three beads are deposited with 20%overlap on the preceding bead. The experimental rune have been conducted by varying welding voltage, wire feed rate, welding speed and NTPD. The objective of this cladding process is to maximize the bead geometry to cover the given surface area in minimum number of welding passes. The bead geometry has been governed by various welding parameters like electrode melting and deposition rate. The use of Taguchi design of experiments enabled to study and rank the process parameters based on their influence on the response. It was found that the wire feed rate contribute more than the other parameters on the weld bead width. The welding speed was decisive in the case of reinforcement height.**

Key words—Gas metal arc welding, Taguchi method, Bead geometry, Microstructure studies, Genetic algorithm, overlapping.

1 INTRODUCTION

Welding is the process of joining two metals. It has its application in many fields such as automobile, civil construction, manufacturing sectors etc. It is widely used in the fabrication of boiler, pressure vessel, nuclear reactor etc. precision control of heat input during welding is more important to ensure bead dimensions and corrosion resistance. The weld deposits were normally linked to the main cord by serious of repeated welding process, the overlapping of weld may complicate the situation even more. In welding plates of different sizes are used depending upon its application related to pressure. The gas metal arc welding has gone into various refinements in the past decades. The gas metal arc welding can produce high efficiency with respect to deposition. [1] The shield metal protect the arc from change in metal matrix during its travel from the nozzle to the plate. Stainless steel produce high tensile strength. The use of stainless steel electrode improves the strength of the weld metal. Stainless steel have a good resistance to corrosion. These steel have good impact strength, making it suitable to cryogenic tests.

The welding process engage vast quantity of heat transfer. It would be far difficult to simulate the process theoretically. This process involves standardization of welding process the specimens are welded with different constrains. [13] The temperature that is obtained for the period of multipass welding affects various mechanical and micro structural parameters.

1.1 20% overlapping model

The single weld be a din joining applications, each layer in the GMAW based deposition process consists of continuous overlapping beads. A simple sketch of the overlapping model is shown in Fig.1. The area of valley and overlapping area in adjacent beads are depicted. The center distance of adjacent bead side fined as d. [3] The view to simplifying the overlapping model, three assumptions are proposed:

1. The cross section profile of single weld be a dissymmetrical.
2. Every weld bead with the same welding parameter has uniform cross section profile.
3. The section profile of a single weld bead remains unchanged during the overlapping of adjacent beads.

1.2 PROPOSAL OF EXPLORATION

The research work was prearranged to be conceded out in the subsequent steps [5]:

1. Evolving the design matrix and steering the experiments as per the design matrix.
2. Recording the responses bead width (W) and height.
3. Emerging the mathematical models to influential the signal to ratio (larger the better).
4. Presenting the effects of ranking the process parameters and the graphical form and scrutinizing the results.
5. Optimization of process parameters to obtain the desired weld bead geometry and dilution.

2 EXPERIMENTAL PROCEDURE

The base material used for experimental work is low carbon structural steel IS: 2062:2011(Grade C), the dimensions of the work piece are 20mm thickness and its length and breadth are 12 and 5 inches. The compositions are followed.

Table 1: Chemical composition of the base plate.

Material	C % Max.	Mn.% Max	S % Max	P % Max	Si % Max
IS2062 C	0.2	1.5	0.04	0.04	0.4

Cladding material is stainless steel 316L electrode and the diameter is 1.2 mm. The compositions for electrode are followed.

Table 2: Electrode chemical composition.

Electrode material	C%	Cr%	Ni%	Mo%	Mn%Si%
316L	0.02	17.8-18.4	11.9	2.2	1.6-20.50-0.80

2.1 GMAW process parameters:

Process factors are plays a very significant vital role in this welding procedure. Parameters to be fixed and change for experimental sage.

Welding speed (WS), welding voltage (WV), Wire feed rate (WFR), Nozzle to plate distance (NTPD)

Fixed variables

These variables are important for the welding process. This will be taken according to the collected works assessment.

1. Percentage overlap – 20%
2. Inter-pass temperature - 150°C
3. Shielding gas type and flow rate – flow 25 lit/min and composition 100%Ar

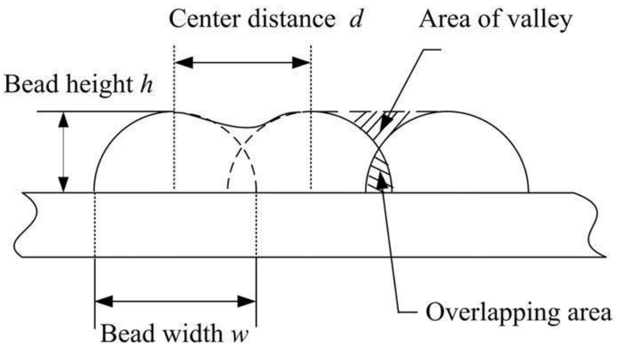

Fig. 1: Sketch of overlapping beads.

3 TAGUCHI TECHNIQUE

Genichi Taguchi has been identified with the advent of what has come to be termed quality engineering. [3] The goal of quality engineering is to move quality improvement efforts upstream from the production phase to the product/process design stage (off-line).As his loss function establishes; his main concern is deviation of a characteristic from its nominal value. Uncontrollable factors (noise) are often responsible for this aberration and, therefore, Taguchi's approach to experimental design has as its goal the design of products/process that are robust to these noise factors.

3.1 Assumptions of the Taguchi method:

The preservative assumption implies that the individual or main effects of the independent variables on routine parameter are separable. In this statement, the effect of each factor can be linear, quadratic or of higher order, but the typical assumes that there exists no cross product effects (interactions) among the specific factors. That means the effect of independent variable 1 on performance parameter does not depend on the different level settings of any other independent variables and vice versa. If at any time, this assumption is desecrated, then the additive of the main effects does not hold, and the variables act together.

3.2 Designing an experiment:

The design of an experiment consist the following steps.
Selection of independent variables

Range of number of level settings for each independent variable
Selection of orthogonal array transmission the independent variables to each column

Conducting the experiments investigating the data
Inference.

The Taguchi arrays can be derived or looked up. Small arrays can be pinched out manually; large arrays can be derived from deterministic algorithms. Usually, arrays can be found online. The arrays are designated by the number of parameters (variables) and the number of levels (states). This is further explained later in this article [11]. Analysis of variance on the collected data from the Taguchi design of experiments can be used to select new parameter values to optimize the performance representative. The data from the arrays can be investigated by plotting the data and performing a graphic analysis, regression, bin yield and Fisher's exact test, or Chi-squared test to test significance [9].

An orthogonal array is a type of experiment where the columns for the

Independent variables are "orthogonal" to one another.
Benefits:

1. Conclusions valid over the entire region spanned by the control factors and their settings
2. Large saving in the experimental effort
3. Analysis is easy

To define an orthogonal array, one must identify:
1. Number of factors to be studied
2. Levels for each factor
3. The specific 2-factor interactions to be estimated

4. The special difficulties that would be encountered in running the experiment

We know that with 2-level full factorial experiments, we. Can estimate variable interactions. When two-level fractional factorial designs are used, we begin to confound our interactions, and often lose the capacity to obtain unconfused estimates of main and interface effects. We have also seen

That if the generators are chosen carefully then knowledge of lower order interactions can be achieved under that assumption that higher order interactions are negligible.

Orthogonal arrays are highly fractionated factorial designs. The information they provide is a function of two things

• The nature of confounding
• Assumptions about the corporal system.

3.3 HEAT INPUT:

$$\text{Heat input} = \frac{60 * V * I}{s} \text{ KJ/mm} \quad (1)$$

V- Welding Voltage (V),
I- Welding Current (Amp),
S- Welding Speed (m/min).

In the present study, three 3-level and 4-factor process parameters i.e. welding voltage, welding speed, wire feed rate and standoff distance are considered. The values of the welding progression parameters are shown. The ranges and levels are fixed based on the screening experiments and AWS reference. The interaction effect between the parameters is not considered.

The total degrees of freedom of all process parameters are 8. The degrees of freedom of the orthogonal array should be greater than or at least equal to the degrees of freedom of all the process parameters. Hence, L9 (3^4) Orthogonal array was chosen which has eight degrees of freedom.

Table 4: Process parameters.

Welding parameters	Units	L1	L2	L3
Voltage	V	20	25	30
Wire feed	m/min	5.0800	7.6200	10.160
Speed	m/min	0.1	0.140	0.180
NTPD	m	0.015	0.019	0.023

DESIGN MATRIX

1	1	1	1
1	2	2	2
1	3	3	3
2	1	2	3
2	2	3	1
2	3	1	2
3	1	3	2
3	2	1	3
3	3	2	1

4 INVESTIGATIONAL RESULT

For the experimental design, an orthogonal array is used. It consists of a set of experiments where the settings of several products or process parameters to be studied are changed from one experiment to another. Results obtained from the experimentation are studied with the help of S/N ratio and regression analysis. By using these results, optimal cutting parameters for maximum material removal rate are obtained. The analysis is made using the software MINITAB 16.

Table 5: Mediocre bead width and height.

Ex	X1 (voltage) (V)	X2 (feed) (m/min)	X3 (speed) (m/min)	X4 (NTPD (mm))	Average height (mm)	Average width (mm)
1	20	5.0800	0.100	15	7	27.77
2	20	7.6200	0.140	19	6.6	28.42
3	20	10.160	0.180	23	6.64	31.94
4	25	5.0800	0.140	23	5.40	23.9
5	25	7.6200	0.180	15	5.78	26.57
6	25	10.160	0.100	19	6.18	35.78
7	30	5.0800	0.180	19	3.67	22.02
8	30	7.6200	0.100	23	6.82	42.36
9	30	10.160	0.140	15	6.86	43.29

Fig 2. Weld bead specimen.

4.1 RESULT IN MINITAB:

Taguchi Analysis: W versus V, F, S, NTPD

Table 6: Response Table for Signal to Noise Ratios
Larger is better

level	V	F	S	NTPD
1	29.84	27.77	30.83	30.03
2	29.40	30.03	29.79	29.00
3	30.71	31.30	28.48	30.06
POC	19.30%	41.04%	27.32%	12.32%
Rank	3	1	2	4

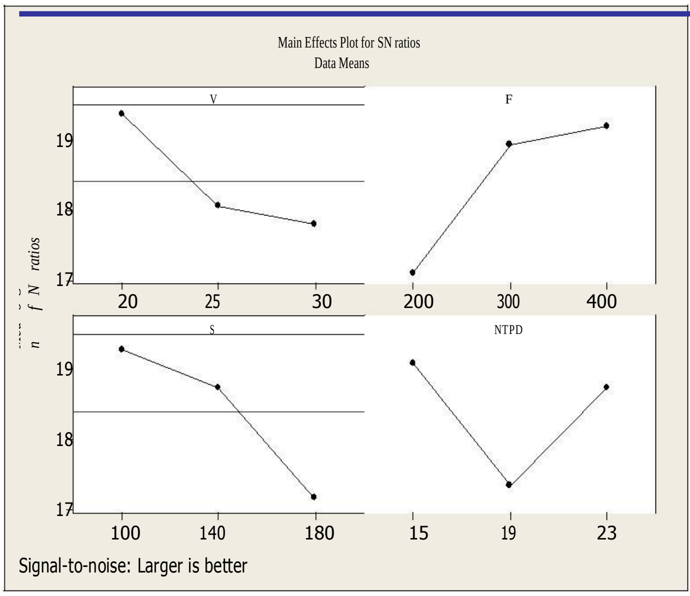

Fig 3: Graph for SN ratio for width.

Response Taguchi Analysis: H versus V, F, S, and NTPD

Table 7 Response Table for Signal to Noise Ratios
Larger is better.

level	V	F	S	NTPD
1	16.58	14.28	16.47	16.29
2	15.24	16.10	15.92	14.50
3	14.90	16.33	14.33	15.92
POC	21.93%	26.72%	27.93%	23.36%
Rank	4	2	1	3

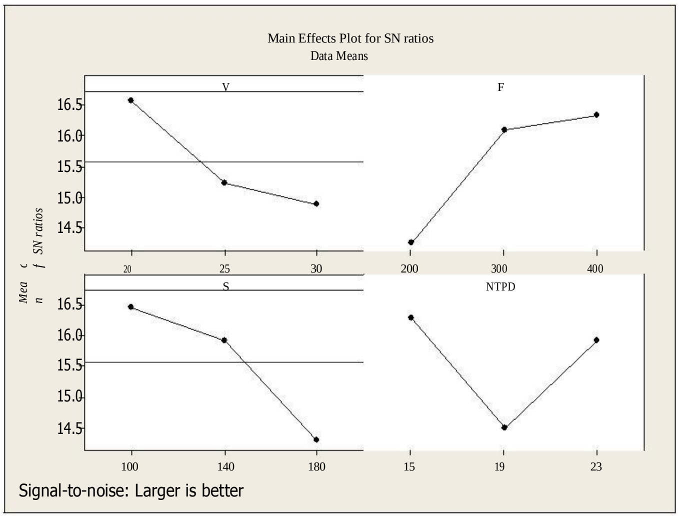

Fig 4: Graph for SN ratio height.

Regression Analysis: W versus V, F, S, NTPD
The regression equation is
WD = 10.7 + 0.651 V + 0.0622 F - 0.106 S + 0.024 NTPD

Predictor	Coef	SE Coef	T	P
Constant	10.75	13.97	0.77	0.484
V	0.6513	0.3351	1.94	0.124
F	0.06220	0.01676	3.71	0.021
S	-0.10575	0.04189	-2.52	0.065
NTPD	0.0238	0.4189	0.06	0.958

S = 4.10425 R-Sq. = 85.7% R-Sq. (adj) = 71.4%

By using Taguchi L9 orthogonal array the response should be optimized using minitab16 software. Further input parameters the best impact solution tabulated and it should be ranked. The graph shows the contributions to the nine combinations are plotted.

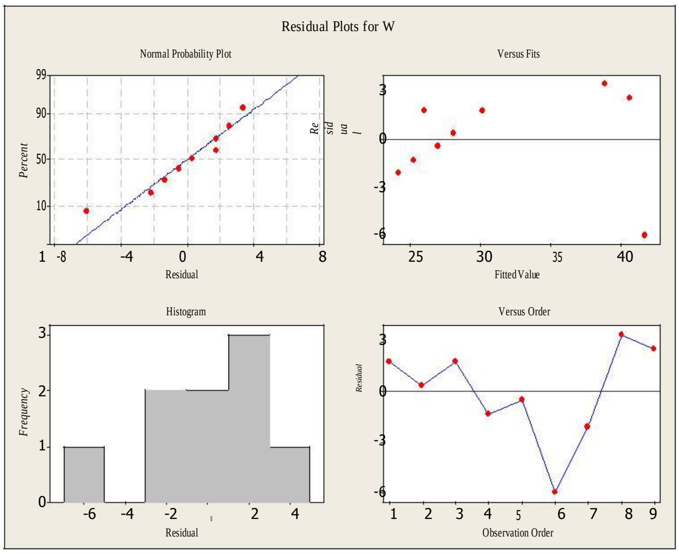

Fig 5: showing the graph for residual plots.

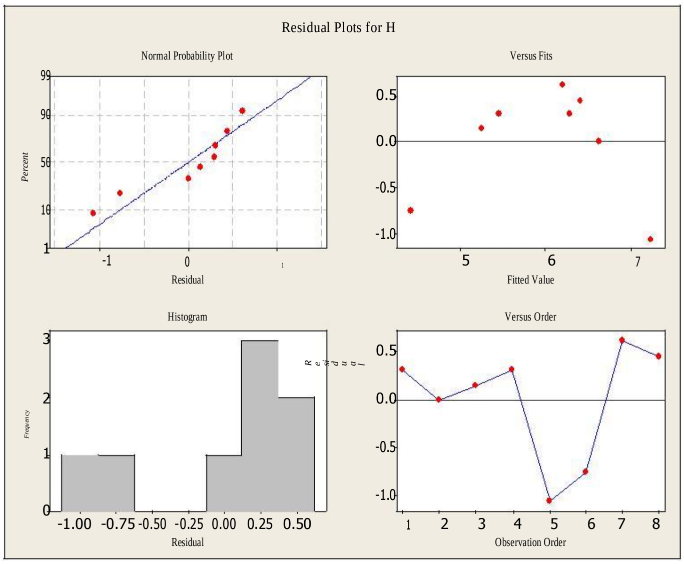

Fig 6: showing the graph for residual plots.

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Regression Analysis: H versus V, F, S, NTPD.
The regression equation is
H = 6.65 - 0.0614 V + 0.00776 F - 0.0119 S + 0.011 NTPD

Predictor	Coef	SE Coef	T	P
Constant	6.654	6.274	1.06	0.367
V	-0.06142	0.09848	-0.62	0.577
F	0.007762	0.004924	1.58	0.213
S	-0.01193	0.01231	-0.97	0.404
NTPD	0.0111	0.1231	0.09	0.934

S = 0.911727 R-Sq. = 69.0% R-Sq. (adj) = 27.7%

5 GENETIC ALGORITHM

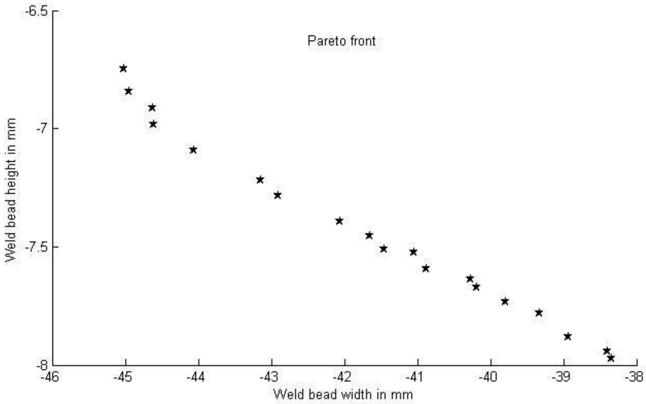

Fig 6: Pareto chart.

The Pareto chart shows the result for weld bead width and height. For the equation W and H

WD = 10.7 + 0.651 V + 0.0622 F - 0.106 S + 0.024 NTPD (2)

H = 6.65 - 0.0614 V + 0.00776 F - 0.0119 S + 0.011 NTPD (3)

Table 7: multi objective GA points W and H

1	-38.3516	-7.9695	20.00649	10.15992	0.100234	15.01442
2	-38.3516	-7.9695	20.00649	10.15992	0.100234	15.01442
3	-45.0257	-6.74719	29.99076	10.15534	0.100287	22.97968
4	-42.9118	-7.28326	27.0302	10.15768	0.10035	15.24317
5	-44.6163	-6.98132	29.62473	10.14834	0.100336	16.78445
6	-40.8857	-7.59228	23.90743	10.15902	0.100269	15.03807
7	-41.0444	-7.52357	24.09859	10.15712	0.100252	16.58083
8	-44.6279	-6.91392	29.52038	10.15542	0.100304	19.23511
9	-44.062	-7.08937	28.79615	10.1526	0.100381	15.92364
10	-45.0257	-6.74719	29.99076	10.15534	0.100287	22.97968
11	-44.9444	-6.84147	29.98479	10.15286	0.100301	20.07115
12	-40.1855	-7.66979	22.81138	10.15623	0.10027	15.88006
13	-40.2756	-7.6379	23.01023	10.15844	0.100732	16.05631
14	-39.8009	-7.72976	22.21768	10.15735	0.100261	15.80643
15	-41.6495	-7.45231	25.05487	10.15711	0.100269	15.9308
16	-38.9373	-7.87866	20.92239	10.15837	0.100305	15.0484
17	-38.4061	-7.94066	20.06409	10.15992	0.100235	15.73023
18	-42.061	-7.39181	25.67238	10.15977	0.100254	15.9898
19	-41.4527	-7.50737	24.77725	10.1597	0.100286	15.06983
20	-43.1548	-7.2162	27.3994	10.14891	0.100328	16.15914
21	-39.3286	-7.77876	21.46107	10.15737	0.100239	16.55212

6 CONCLUSION

This is the remaining signal to noise ratio graph plotted and get the secluded input parameters belongs their contribution for bead width.

1. To using this signal to noise ratio larger the better solution welding wire feed rate give more contribution to bead width so it ranked first. It is give 41.04% contribution.
2. Welding Speed is the second raked position and it is give 27.32% contribution to the bead width.
3. Welding voltage is the third ranked position and it is give 19.30% impact to the response.
4. Nozzle to plate distance is the least and final ranked position and it is 12.32% contributing.

The secluded input parameters belongs their contribution for bead height.

1. To using this signal to noise ratio larger the better solution welding speed give more contribution to bead width so it ranked first. It is give 27.93% contribution.
2. Welding wire feed rate is the second raked position and it is give 26.76% contribution to the bead width.
3. Nozzle to plate distance is the third ranked position and it is give 23.36% impact to the response.
4. Welding voltage is the least and final ranked position and it is 21.93% contributing

The multi objective GA Pareto chart is drawn by mat lab 10 for the weld bead width and height.

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