Performance characteristics of GMAW process parameters of multi-bead overlap weld claddings

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Abstract. The effect of Gas Metal Arc Welding process parameters on the bead geometry of stainless steel (SS) claddings can be studied using statistical Taguchi L9 design of experimental model. In this study deposits were made with continuously varying weld bead overlaps of 0 – 100%. Cladding is proposed to impart corrosion inhibition properties to the low carbon structural steel plate. Selection of welding process parameters affects the arc stability, heat input deposition rate and quality of the surfaced layer represented by the percentage dilution. Minimization of heat input leads the reduced deposition rate and increased occurrences of weld bead defects like porosity, lack of fusion and cracking. In this context, it is important to identify the extent of influence exerted by the controlled welding parameters on the bead geometry. The reinforcement dimensions play an important role in the cladding process. Stainless steel claddings are deposited by automated Gas Metal Arc Welding (GMAW) process by using Taguchi L9 design of experiment. The selected input variables are Welding voltage (WV), Wire feed rate (WFR), Welding speed (WS) and NTPD. The responses identified governing the bead geometry like bead width (w) and height of the reinforcement (h) in different bead overlaps like 0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100%. The paper also explores the variation in the bead geometry at different levels of overlap percentages including hardness evaluation.

Keywords. Gas metal arc welding; Bead geometry; Cladding; Taguchi; Stainless steel; Hardness; Optimization;

1. Introduction
The weld metal bead overlapping is the operation of depositing relatively very thick layer by layer over a parent metal on low grade carbon steel, because lack of corrosion resistant. In industries consistently to increasing the anti-corrosive resistant properties of low carbon steel (mild steel) by using the selective filler wire as stainless steel claddings (SS 309L) at minimum thermal sources. The claddings are widely applicable for ships bottom surface, aerospace, railway, food, service life of the
components and chemical container, civil construction, boilers industries, etc [1-3]. There are more fusion arc welding process are having to performing for cladding, the gas metal arc welding (GMAW), flux cored arc welding (FCAW), laser cladding and gas tungsten arc welding (GTAW) is the potential for even bead surface appearance, higher build-up rate and easily flux removable [4-8]. Stainless steel surface weld cladding is the process of low grade carbon content materials; it develops the coated layer of stainless steel quality bonded surfaces of the parent metals. In the stainless steel having the smooth proportions of austenitic and ferrite content it will develop corrosion resistant properties. The stainless steel cladding provides the excellent properties of mechanical strength. Fusion welding is the ability to meet the industries requirements by using surface layered cladding technique [9-16]. The physical property of cladded material defines from the weld bead geometry, the filler wire deposition on the base surface through wire coated material melted and bonded. The quality of weld bead geometry and desired properties can be obtained in the cladding research [17-21]. In the metal arc welding technique, the selection of input process parameters is the significant role to achieving the optimum overlap percentage of weld bead surface quality in multiple responses [22-24]. This objective can be identifying the relationship between the input process parameters and output variables in form of developed mathematical experimental investigation models. In recent researches have established the efficient way of using Design of Experiment (DOE) techniques in the welding input and output variables. The statistical taguchi quality improvising tool is based on performing evaluation of experimentation models to test and analysis of variance of a set of control variables to a set of predicting parameters (or independent variables) by considering experiments in taguchi’s orthogonal array with an focus to attain the optimum selection of the control parameters [25-27]. The identified mathematical models functions were used to perform the computer programme simulation, process optimization (maximizing or minimizing) and evaluation of the welding parameters with respect to its process variables [28-31]. The bead profile consist the number of welding layer filler passes requires covering the desired variables. Since, verifying mechanical properties and dilution of filler wire in parent metal have investigated from optimized samples. The mechanical property characterization techniques evaluated for predicting the various clad surface area characteristics like hardness [32-33]. The objective of surface cladding process is to make a maximizing the bead width and height of reinforcement with determination of mechanical properties in overlapped structure. Therefore the above study, insights the GMAW cladding trial-run-experiment demonstration approach can be performed to establishing the parameter selection and experimental limits controlling process. The metal inert gas welding experimental setup carries a manipulator, shielding gas, welding machine, wire feeder, torch, and nozzle. In the designed experiments that can findings the most influential process variables from a set of input parameters. To provide weld quality by improving the prediction of weld clad percentage 0-100% sequence level and control the defects in weld metal cladded surface.

2. Experimental investigation
The constant current gas metal arc welding machine and wire feeder are connected to performing the cladding operations. The electrode was 1.2 mm diameter SS 309L (25%Cr and 7%Ni) and parent metal is IS:2062 low grade carbon structural steel. The composition of the electrode and parent metal is shown in table 1. The process supplied gas mixture contains 80% Argon and 20% CO₂ was supplied at a rate of 24 lt/min. The development mathematical models were illustrated in the following sections. The experimental setup is shown in figure 1.

| Table 1. Composition of electrode and base metal |
|-----------------------------------------------|
| **Material**          | **C** | **Mn** | **Si** | **S**  | **P**  | **Cr** | **Ni** | **Mo** | **Cu** | **N**  | **Fe** |
|-----------------------|-------|--------|--------|--------|-------|--------|--------|--------|--------|--------|--------|
| Electrode             | 0.03  | 2.12   | 0.58   | 0.005  | 0.018 | 24.5   | 13.60  | 0.75   | 0.06   | 0.28   | Balance |
| Base Metal            | 0.203 | 0.90   | 0.90   | 0.029  | 0.017 | 0.02   | 0.020  | 0.028  | 0.096  | --     | Balance |
2.1. Establishing limits and parameters coding
The process parameters range and limits established by conducting trial runs followed by different ranges. The limits of each process parameters were found by differing single parameter at a time and keeping all the others unchanged. The limits were coded as level 1, level 2 and level 3 in the unavailability of defects like metal cracking, discontinuity in weld flow and lack of fusion. The intermediate levels were determined by using the “(1)” and listed in the table 2.

Table 2. Process parameters levels and coding

| Parameters       | Units       | 1  | 2  | 3  |
|------------------|-------------|----|----|----|
| Welding voltage  | Volts       | 25 | 28 | 30 |
| Wire feed rate   | inch/min    | 6.64| 7.17| 8.12|
| Welding speed    | mm/min      | 31 | 34 | 37 |
| NTPD             | mm          | 8  | 10 | 12 |

2.2. Developed design matrix
The experimental features required for the development of simulation models for the GMAW process were stored from the experimental run based on the Taguchi L9 designed orthogonal array. The design matrix consists of nine experimental runs in different combination. The experimental parameters combinations in coded form with predicting responses like weld bead width and reinforcement height were presented in the Table 3.

2.3. Investigation task and observation
The base plate fully cleaned through the surface of the metal by using fine grade emery paper sheets to remove any oxide layer and residues using the fine grade sand paper. The experimental combinations were taken from the table 3, at differently to introduce the operations in the experimental settings error. After finishing the 9 experimental runs we should measure the output variables. The weld bead quality values like weld bead width (W), height of reinforcement (H) and mechanical property evaluation. The figure 2, shows the experimental runs specimen number 1 to 9 preparing ready to measure the bead geometry work.
2.4. Construction of Mathematical model

The experimental based output values with the process parameters were developed as mathematical functions given by the “(1)”.

\[ \text{Responses } R = f(n_1, n_2, n_3, n_4) \]  

(1)

Where the \( n_1 \), \( n_2 \), \( n_3 \) and \( n_4 \) are selected process parameters wire feed rate, welding voltage, welding speed and nozzle to plate distance respectively. These were optimized to developing mathematical equation by using statistical Minitab software. The evaluated optimization technique produces the research reports effects for making for modeling, design for controller and welding process variables optimization. The functions reveal the highest level sequence of statistical Taguchi quality improvising tool to findings the optimum variables and the gas metal welding process optimization. In this model used to picking the better output oriented GMAW welding process combinations.

2.5. Mechanical Properties: Hardness

The mechanical properties of the mild steel base plate as well as cladded of the weld overlay SS309 steel are presented in figure 3. Mechanical strength of the cladded area was determined in various areas. All the nine experimented specimens of the welded region were examined at under the 150kgf in the Rockwell hardness measuring instrument. In the hardness interaction values for the weld clad overlays and sectioned sample are shown in figure 10. The Rockwell hardness observed average data values are plotted in the graphical form is shown in figure 3. From the each experiment the 0 to 100% (10 specimen) weld bead surface has been tested in hardness, finally which is converted to take average range value by single experiments.
Figure 4. Weld bead sectioned samples (Each exp. 10 samples)

Table 3. Developed matrix design

| Ex. No | Levels of parameters |
|--------|----------------------|
| Unit   | $X_1$ V | $X_2$ m/min | $X_3$ cm/min | $X_4$ mm |
| 1      | 20      | 6.64        | 31           | 8        |
| 2      | 24      | 7.17        | 34           | 10       |
| 3      | 20      | 8.12        | 37           | 12       |
| 4      | 24      | 6.64        | 34           | 12       |
| 5      | 28      | 7.17        | 37           | 8        |
| 6      | 24      | 8.12        | 31           | 10       |
| 7      | 28      | 6.64        | 37           | 10       |
| 8      | 24      | 7.17        | 31           | 12       |
| 9      | 24      | 8.12        | 34           | 8        |
Table 4. Measured variables output responses

| E.N.o. | Width/Height (mm) | Weld clad overlap (%) |
|--------|-------------------|-----------------------|
|        |                   | 10%  | 20%  | 30%  | 40%  | 50%  | 60%  | 70%  | 80%  | 90%  | 100% |
| 1      | W                 | 13.54| 12.56| 12.36| 11.58| 12   | 10.4 | 10   | 9.22 | 10.6 | 11   |
|        | H                 | 2    | 3.5  | 4    | 4.6  | 4.6  | 4.6  | 5    | 5    | 5.4  |
| 2      | W                 | 17   | 16.28| 15   | 14.32| 13   | 13   | 11.38| 10   | 8.64 | 11.4 |
|        | H                 | 1    | 3    | 3    | 4    | 4.3  | 4.3  | 4.7  | 4.7  | 5    | 5.7  |
| 3      | W                 | 13.4 | 14   | 16   | 13   | 11.7 | 12   | 11   | 9    | 7    | 7    |
|        | H                 | 2.8  | 4    | 4.1  | 4.9  | 4.9  | 6.2  | 7.8  | 8    | 8    | 7.8  |
| 4      | W                 | 15   | 14.71| 13.3 | 12.54| 11.78| 12   | 11.54| 10.4 | 9.43 | 9.62 |
|        | H                 | 2    | 3    | 3.5  | 4    | 4.4  | 4.4  | 4.5  | 4.7  | 5    | 5    |
| 5      | W                 | 16.5 | 16   | 15.3 | 14.71| 13.54| 12.33| 11   | 9.43 | 11.34| 14   |
|        | H                 | 2    | 3.7  | 3.8  | 3.8  | 4    | 4    | 4.4  | 5    | 5    | 5.4  |
| 6      | W                 | 18   | 18.62| 17   | 15.52| 14.52| 13.75| 14   | 12.54| 11   | 13   |
|        | H                 | 2    | 4    | 4    | 4.3  | 5    | 5    | 5    | 5.4  | 6    | 6.5  |
| 7      | W                 | 20   | 18   | 17   | 16.1 | 15   | 13   | 13   | 11   | 11   | 13   |
|        | H                 | 2    | 3.45 | 4    | 4    | 3    | 3.84 | 4    | 4    | 4.25 | 5    |
| 8      | W                 | 20   | 19   | 17   | 16.4 | 15   | 13.54| 13   | 12   | 10.3 | 13.42|
|        | H                 | 2    | 3    | 3.3  | 3.4  | 4    | 4.2  | 4.5  | 5    | 5.5  | 6    |

6
The reduced models were constructed by selecting input variables based on their highest level on the predicted values. The insignificantly contributing parameters were eliminated with a critical value of level of significance of 0.75. If the level of Significance of the interactions is above the critical value then it will retain in the reduced models. The reduced models were presented by the “(2) and (3)”. 

Figure 5. Hardness measured values

Figure 6. Bead width (W) interaction effect plots
The response of the weld cladding process is dependent on the heat input, deposition sequence and maintaining pressure on the welding machine. The metal coated filler wire was melted and deposited the substrate, the coated weld structure quality mainly depends upon the bead geometry, it consists of weld bead width and height of reinforcement. The deposition and feed rates of the filler wire regulates the better weld geometry dimensions. These functional movements will not create the major impacts in welding selected parameters. The main focus of this research to carry the minimum level of dilution percentage and required deposition rate. It is mainly subjected with heat input to meet the optimum dimensions of bead geometry. From the graphical representation of fig. 4 and 5 shows that weld bead width and height of reinforcement the essential effect plots of input process parameters. To developing the optimum weld bead geometry produced by various overlapped percentages of welding process like 0-100%, the observed response factors in different experimental investigation should be carried by the weld overlap. The maximizing functional response models involves to determining the required level variables that are within the feasible regions is used to setting the quality process objective without any deviation.

4. Result and Discussion
The L9 experimental weld structure overlap outputs were carried out in this research investigation. From the table 4 shows the observational work of selected responses (W and H) during different overlap bead dimensions as per the design matrix. The observed regression equation results provide the insight into the most significances process variables. The multi-layered weld bead dimensions vary like bead width 15 mm to 20 mm and height of reinforcement varies from 5 mm to 8 mm. The optimum hardness was seventh and eighth experimental overlap percentages measured to achieve on higher value from the Rockwell hardness scale equipment. The regression models were developed for bead width and height of reinforcement are given by equations (1) and (2) respectively.

The developed regression equation in bead width

\[
\text{Bead Width} = 4.88 - 0.467 X_1 + 0.317 X_2 - 0.283X_3 + 0.117 X_4
\]

The developed regression equation in height of reinforcement

\[
\text{Bead Height} = 11.1 + 1.30 X_1 + 0.325 X_2 - 0.213 X_3 - 0.262 X_4
\]
5. Conclusion
In this Gas metal arc welding (GMAW) multi-pass bead overlap (0 – 100%) in experimental process effects on the variables carried out, the analytical regression equation were developed using four factors with three levels statistical quality Taguchi L9 orthogonal array used for the stainless steel SS309L weld surface metal cladding process in the IS:2062 graded low grade carbon mild steel. In these results, the most dominant parameters are welding voltage and welding speed, here the welding voltage increases it leads to improve the bead width. In case the welding speed increases, it produces minimum bead width. From the different weld bead overlaps 0-100% were bead dimensions are measured bead width and height. In each one of experiment ten set of dates have collected like 0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 100% bead overlaps. It also examined response factor values that are maximum width and height, the experiment number 3 and 7 showed the higher range output values in this investigation work. The observed graphical response plots defined the bead geometry parameter interaction also the hardness strength. As the view of mechanical hardness characters are consistent during the standard deposition supply of filler materials.

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