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INVESTIGATION ON FERRITE NUMBER OF STAINLESS STEEL 304 BY OPTIMIZING THE PARAMETERS USING RESPONSE SURFACE METHODOLOGY

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Abstract

Corrosion in stainless steel 304 that joined by using MIG weld procedure. metal-inert gas welding (MIG) process it is use widely join in the stainless-steel metal parts in various metal joining applications. Corrosion is the major problem in stainless steel that degrades the material properties and mechanical strength. The corrosion in the stainless steel can be identified by using the ferrite number. This project is aims to reduce the ferrite number of stainless steel 304 that causes corrosion after the welding process. The most influencing factors such as welding current, speed, and angle are selected and their levels are fixed. The Response Surface Methodology (RSM) utilized to optimize the indicated trials are carried out using process parameters and an optimization parameter. With the optimized parameters the experiment parts were validated with the ferrite number to reduce the corrosion in a stainless steel.

Keywords: MIG welding, optimizing parameter, Response surface methodology.

I. Introduction

During the metal inert gas (MIG) welding procedure, a continuous solid wire electrode is supplied through a welding gun and into the weld pool. to fuse the two base materials together. The majority of the time, thick and massive materials are welded. materials for welding include carbon steel, stainless steel, and aluminum [1]. The most popular variety of stainless steel is austenitic. In addition to having outstanding mechanical qualities over a wide temperature range, it offers excellent corrosion and heat resistance although They are prone to corrosion when being welded. The issue of corrosion affects the steel structure and causes it to fail [5]. The welded specimen can be controlled using response surface methods, and the welding current, welding angle, and welding speed can control corrosion [2]. welding current is the most important factor Because it impacts bead shape, regulates the pace at which electrodes melt, and consequently regulates the rate at which material is deposited. The depth of fusion or diffusion will also be too high if the current is too high at a particular welding speed, which increases the risk that the resulting weld will tend to melt through the metal being connected. Moreover, high current results in excessive reinforcing of the electrodes being wasted, a burrowing arc, and an undercut. Moreover, too low current causes an unsteady arc, insufficient penetration, and over lapping [8]. In the MIG welding process, welding current is closely correlated to stick out length; if stick out length is increased, there will be less current concentration, which increases the likelihood of insufficient heating. The ideal flux cored arc welding Palani and Murugan invented the stainless-steel cladding weld bead form. They discovered that the ferrite material present during cladding causes pitting corrosion, which is amplified by the proportion of dilution [3].

R. Prabhu and T. Alwarsamy [11] evaluated the influence of process parameters on the ferrite number when cladding austenitic stainless steel 317L using the Pulsed Metal Inert Gas (MIG) welding technique. To forecast and create the mathematical model for process factors including welding current, welding speed, and contact tip to work distance on ferrite number, a central composite rotatable design based on response surface methodology (RSM) was used. Using the analysis of variance method, it was discovered that the created mathematical model was impressive. The created mathematical model can be used to control and measure the amount of ferrite in austenitic stainless-steel cladding. Graphical representations of the input process parameters' direct and indirect effects are provided.

R. Sudhakaran [2] studied that response surface methods to examine the impact of process variables on the ferrite content of during the gas tungsten arc welding procedure on stainless steel of grade 202. They measured the ferrite number using a Diagram of Delong and ferrite scope. The significance of predicting Discussion is had regarding the delta ferrite content of stainless-steel welds. in this abstract, which builds on research done by M. Vasudevan on producers and consumers to ensure that the weld has the prescribed minimum or maximum level of ferrite. Several techniques have been used to forecast the delta ferrite content, such as constitution diagrams and the Function Fit model, and models of neural networks with feed-forward and back-propagation. The training data may be overfit even though it has been asserted that the neural network approach is more accurate. To avoid over-fitting, The delta ferrite content in stainless steel welds has been predicted by a Bayesian neural network (BNN) model. It is discovered that while determining the delta ferrite concentration in stainless steel welds, the BNN model performs badly.

Kamal Pal [13] examined the Weld quality is a challenge for industries to maintain because of inadequate arc stability and post-welding distortion. This study changed the welding torch angle and pulse voltage settings for Pulsed metal inert gas (P-MIG) welding to increase the weld quality and efficiency. It was found that the peak voltage of the pulse was the key factor controlling the pulse voltage. transverse shrinkage and angular distortion. The welding process was observed using a variety of sensors, and a significant correlation between arc sound and transverse distortion and metal deposition was discovered. Also, the study extracted welding arc sound's frequency domain properties and connected them to process parameters. The given literatures are indicating unequivocally how difficult it is for many research projects to determine and choose the process parameters for the cladding process. Numerous researchers have used a central composite rotatable design strategy based on response surface methodology thus far for the development of mathematical models and the analysis of process variables. Thus, there was little discussion of the study that attempted to predict the ferrite number during pulsed MIG welding. There have been few attempts to create mathematical models that can predict the ferrite number in nickel and chromium alloys. Also, very few research have looked into the possibility of predicting ferrite number from process variables. The impacts of process factors on the ferrite number in MIG welding when welding 304 stainless-steel to steel plate were examined in the current investigation using the following methodology.

2.0 Methodology

From the literature survey the issue of corrosion in stainless steel 304, which is a commonly used material in industrial applications due to its excellent corrosion resistance properties [9]. However, despite its high resistance to corrosion, stainless steel 304 is still prone to corrosion under certain

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conditions, such as high temperature or exposure to certain chemicals. The obtained methodology for this work is illustrated in fig 1.

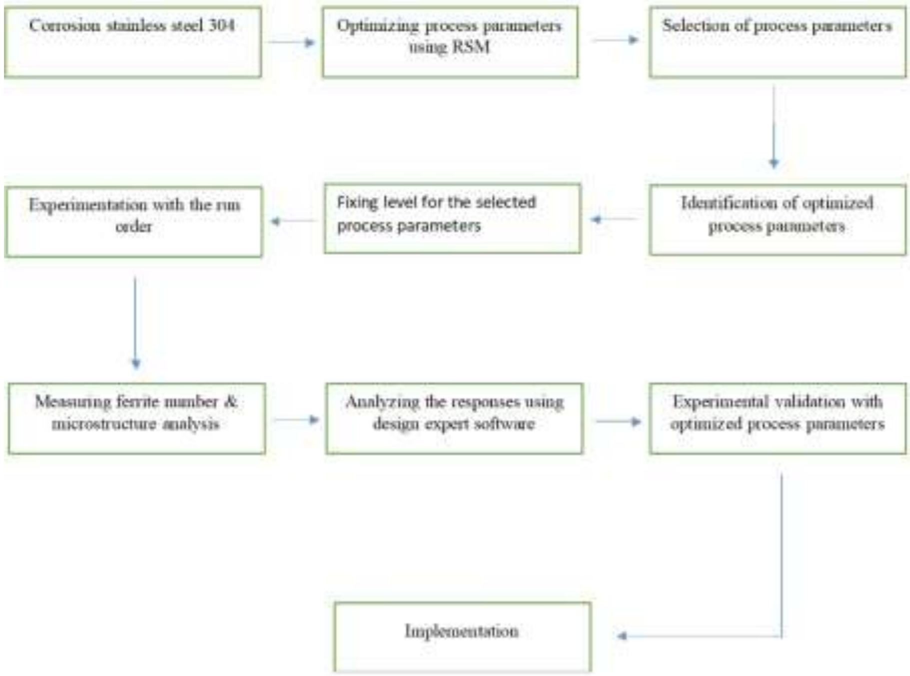

Figure.1 Methodology block diagram

Based on this information, to determine how these parameters affect the ferrite number and corrosion resistance of stainless steel 304, established the welding parameters and created an experimental run order. used Design Expert software to analyze the experimental results and collect data on the ferrite number and corrosion properties of the samples. After analyzing the data, the researchers optimized the welding parameters using the Design Expert software [7]. then conducted an experiment validation to ensure that the optimized parameters were effective in reducing corrosion resistance. The experiment validation involved testing the stainless-steel samples under different conditions to confirm that the optimized parameters were indeed effective in improving the stainless steel 304's resistance to corrosion.

Finally, the implemented the optimized welding parameters in the industry to increase type 304 stainless steel's ability to resist corrosion. This could have important implications for industrial applications where stainless steel 304 is used [16], as improved corrosion resistance can help to increase the lifespan and durability of equipment and structures made from this material.

3.0 Experimentation

3.1 Methods and Materials

Examined how the ferrite number of stainless steel 304, the investigation material, was affected by independent factors (welding current, welding gun angle, and welding speed). The ferrite number is used to calculate the amount of ferrite in steel, which is regarded as a dependent variable in this investigation. The study used a Box-Behnken design, which is a type of experimental design that allows for the efficient exploration of a design space with fewer experiments. The design involved creating trials with different combinations of the independent variables, and measuring the resulting ferrite number for each trial [22].

To analyze the data, the study used a quadratic regression model, which is a statistical technique that allows for the modelling of a measure of how the independent and dependent variables are related. The model was then validated and the significance of the independent variables was using the analysis of variance to determine (ANOVA). The model's goodness of fit was evaluated, and the model's assumptions were verified, by doing residual analysis.

3.2 Experiment Design Using the Response Surface Approach

The welding technique known as RSM, or response surface methodology, optimizes welding parameters such as welding current, welding speed, and electrode angle to produce welds with the desired quality and characteristics. Weld strength, hardness, or micro-structure may be the response variable of interest in welding and are all impacted by different process parameters. A mathematical model that explains the connection between these process variables and the weld quality can be created using RSM. by changing the levels of the welding parameters and monitoring the response variable,[31] RSM requires designing a series of experiments. The primary impacts of each parameter and their interactions are then included in a mathematical equation that models the response. Any combination of welding parameters can be used to predict the reaction using the model.

The expected response as a function of the welding parameters can be shown as a contour or 3D plot on the response surface. The best parameter settings that will result in the required weld quality can be found using this surface. As well as estimating the ideal parameter values in order to obtain the appropriate weld quality, The benefit of the various welding parameters and their interactions can be evaluated using RSM. The use of RSM can help welding parameters be optimized and fewer experiments are needed to attain the desired weld quality[15]. It can save costs related to trial-and-error experimentation and increase welding process productivity and efficiency.

3.3 Box-Behnken

A form of experimental design called to examine how several variables affect a response variable, a box-Behnken design is utilized. It is a sort of response surface methodology (RSM) design that, in comparison to other experimental designs, enables the effective exploration of a design space with fewer experiments. The Box-Behnken design entails conducting a series of tests with a range of levels for each factor while maintaining the status quo for the other factors. These layers are combined in different ways throughout the design. The tests are centre at a location close to the centre of the design space, and the values of each element are chosen to be equally spaced from one another. With fewer experimental runs than other designs, the design is renowned for its effectiveness in developing trustworthy and accurate models [7].

Using Box-Behnken design, it is feasible to combine welding parameters like welding gun angle, welding speed, and current during the optimal method to get the desired weld quality. A decent approximation of the process' response surface can be obtained using the Box-Behnken design with the least number of experimental runs, which conserves time and resources. The design can also assist in determining the important variables and how they interact, as well as in estimating the best values for each variable to obtain the preferred welding quality. The use of Box-Behnken design can increase welding process productivity and efficiency while lowering the need for costly experimentation.

3.4 Design expert software

Design-Expert is used to analyze experiments and improve processes. It is frequently used in the welding industry to improve welding procedures and research the connection between welding process variables and the quality of the produced welds. Design-Expert software makes it possible to plan, evaluate, and optimize tests. ANOVA, response surface methodology (RSM), and graphical displays of experimental data are just a few of the statistical tools and methods included in the software that assist users in recognizing and comprehending the link between welding process parameters and the final weld quality [8].
In order to effectively explore the design space with fewer tests, the programme offers a variety of design alternatives, such as the Box-Behnken design, which is frequently used in welding experiments. Obtaining the necessary weld quality requires, the software also offers tools for modelling the response surface, evaluating the importance of the process factors, and optimizing the process parameters. The experimental results can be shown using a variety of graphical displays, such as contour plots, surface plots, and 3D plots, thanks to the Design-Expert software. These visualizations can assist users in determining the ideal welding process parameters and in comprehending the connection between welding process variables and the quality of the finished weld. Overall, Design-Expert software is a useful tool for individuals involved in welding since it can increase welding processes' productivity and efficiency, lessen the need for trial-and-error testing, and enhance the uniformity and quality of welds.

3.5 Reason for the selected parameter

The selection of welding current, welding experiments use welding speed and welding gun angle as factors. can be based on several factors, such as the desired weld quality, the material being welded, and the welding process being used. Here are some possible reasons for selecting these parameters.

- Welding speed: During the welding process, welding speed can affect the heat input, cooling rate, and solidification rate, which in turn can affect these mechanical properties and microstructure of the joint [12]. To obtain the desired weld quality, the welding speed can be adjusted to optimize the heat input and cooling rate. Welding speed can affect process productivity as well, making it an important metric to optimize for cost-effectiveness.

- Welding current: is a crucial factor in determining how much heat is produced during the welding process. It may have an impact on the weld quality by affecting the weld penetration, weld width, and weld bead form. By adjusting the welding current [2],it is possible to optimize the heat input and penetration depth to obtain the appropriate weld quality.

- Welding gun angle: The welding gun's angle can have an effect on the geometry and penetration of the weld. the appropriate weld quality can be attained [11],the gun angle can be changed to maximize the weld bead geometry, penetration, and fusion.

All things considered, the choice of these parameters in welding experiments can be dependent on the desired weld quality, the material being welded, and the welding procedure being employed. The chosen parameters are provided in the table 2.

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4.0 the components utilized in experiments

Two stainless steel 304 plates with a 3mm thickness were used for the current study. This substance is employed frequently in industries. are shown in table 1.

Materials	*C%*	*Si%*	*Mn%*	*P%*	*S%*	*Cr%*	*Ni%*
Base material	0.08	1.00	2.00	0.045	0.030	18.0-20	8.0-10.5
Filler wire	0.03	0.65	2.5	0.04	0.03	20	15

Table 1. Base substance and the filler wire Chemical composition Table

Thick wire with a 0.80 mm diameter was employed as filler wire, and a plate with a 3 mm thickness served as the base material. Table 2 displays the chemical make-up of the filler wire and base material.

Table 2 Levels and Selected Parameters

SI.NO`	**PROCESS PARAMETERS**	**SYMBOL**	**LEVELS**		
			-1	1	+1
1	Welding current (Amps)	I	80	100	120
2	Welding speed (mm/min)	S	100	115	130
3	Welding angle (Degree)	A	70	80	90

4.1 Experimental work

Figure.2 Welding process

Figure.3 Cutting process

The reported experiment examined the effects of various welding process variables, particularly the welding gun angle, welding speed, and welding current. Utilizing design expert software, which developed a run order to guarantee that each test was carried out consistently and precisely, the experiment was carried out in the fig 2&3. The chosen parameters were established for the experiment to start in accordance with the run order produced by the design expert programme. A given degree of welding gun angle, a specific rate of welding speed, and a specific level of welding current were all set. Following the welding procedure, the samples underwent cutting and grinding procedures. To ensure accuracy and uniformity [1], the cutting and grinding procedures were also carried out in accordance with a predetermined protocol.

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To ascertain the effect of the various parameters on the welding process, the experiment's findings were noted and examined. This analysis evaluated the weld's quality, the existence of any flaws, and the effectiveness of the welding procedure. Conclusions and suggestions for enhancing the welding process were made using the data gathered throughout the experiment. This experiment utilized design expert software to conduct a thorough and methodical study of the welding process. The results were accurate and dependable since the settings were carefully chosen and the experiment was carried out in accordance with a predetermined protocol. The results of this experiment can be applied to streamline the welding procedure and enhance the effectiveness and quality of the welds.

4.2 Experimental methods

In this study in order to optimize the welding circumstances, response surface methods are used to assess stainless steel 304's ferrite number. Welding current, voltage, and speed's effects on the ferrite number were investigated in a series of experiments. are investigated. Using a central composite design (CCD) strategy, which involves changing the welding parameters within a predetermined range, the tests were created. To optimize the welding process parameters, the ferrite number is measured using a ferrite meter, and the data is evaluated using response surface approach and the welded specimens are shown in figure 4.

Figure.4 Welded Specimens

2.3 Experimental process and specimen preparation and measurement of the ferrite number

To create the test specimen, the parameters are selected and welded plates are, without changing the bead geometry or surface roughness, The specimen's top surfaces were grounded as flat surfaces. After that, it was polished to a mirror finish using metallurgical techniques. A magnetic field is applied to the specimen once it has been set inside the ferrite meter. The ferrite number is then determined by measuring the steel's magnetic response and using that information. On the 17 specimens' prepared surfaces, seven Values are measured along the direction of the deposition, and their averages are recorded for each specimen are shown in table 3.

Table 3 OUTPUT RESPONSE OF FERRITE NUMBER

SI.NO	STD	RUN	FACTOR 1 A: WELDING CURRENT Amps	FACTOR 2 A: WELDING SPEED mm/min	FACTOR 3 A: WELDING ANGLE Degrees	RESPONSE FERRITE NUMBER
1	17	1	100	115	80	2.6
2	2	2	120	100	80	1.4
3	16	3	100	115	80	2.3
4	9	4	100	100	70	2.6
5	12	5	100	130	90	2.6
6	1	6	80	100	80	1.8
7	10	7	100	130	70	1.7
8	3	8	80	130	80	1.2
9	4	9	120	130	80	1.5
10	13	10	100	115	80	2.5
11	8	11	120	115	90	3.9
12	7	12	80	115	90	3.2
13	6	13	120	115	70	2.5
14	5	14	80	115	70	3.1
15	14	15	100	115	90	1.9
16	15	16	100	115	90	2.5
17	11	17	100	100	80	1.6

ANOVA analysis

Table 4 ANOVA table for test of significance

Source	**Sum of squares**	**DF**	**Mean square**	**F-value**	**P-value**	
Model	7.77	9	0.8637	11.10	0.0022	significant
A-welding current	3.78	1	3.78	48.61	0.0002	
B-welding speed	2.10	1	2.10	27.01	0.0013	
C-welding gun angle	0.1250	1	0.1250	1.61	0.2455	
AB	0.3600	1	0.3600	4.63	0.0685	
AC	0.1225	1	0.1225	1.57	0.2494	
BC	0.5625	1	0.5625	7.23	0.0311	
A2	0.0038	1	0.0038	0.0487	0.8316	
B2	0.4312	1	0.4312	5.54	0.0508	
C2	0.2527	1	0.2527	3.25	0.1145	
Residual	0.5445	7	0.0778			
Lack of fit	0.5325	3	0.1775	59.17	0.0009	significant
Pure error	0.0120	4	0.0030			
Cor total	8.32	16				

ANOVA is a statistical method for evaluating how well a model predicts the outcome of trials. This is a summary of the response quadratic model's analysis of variance, which determines the contributor who significantly affects the output factor. The significance of the model is suggested by the table model's F-value, which is 11.10 is shown in table 4.

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Table 5 Adjusted R^2

Std	0.2789		**R^2**	0.9345
Mean	2.29		**Adjusted R^2**	0.8504
C.V. %	12.19		**Predicted R^2**	-0.0266
			Adeq precision	11.8626

Created mathematical model

The effects of process were investigated using the mathematical model mentioned above factors on ferrite number. It is obvious that the reaction is increased by positive linear coefficient values and decreased by negative values. In order to confirm that the constructed mathematical model was adequate, Additionally, the analysis of variance method was used. The F-value of 11.10 indicates Hence, at a 95% degree of confidence, the model is significant. The coefficient of determination R2 and adjusted coefficient of determination R2 are calculated to evaluate the fitted model's correctness. The calculated R2 score should be between 0 and 1, hence the fact that R2 is 0.96, which is quite near to 1, indicates that the generated model is sound is shown in table 5.

A scattergram

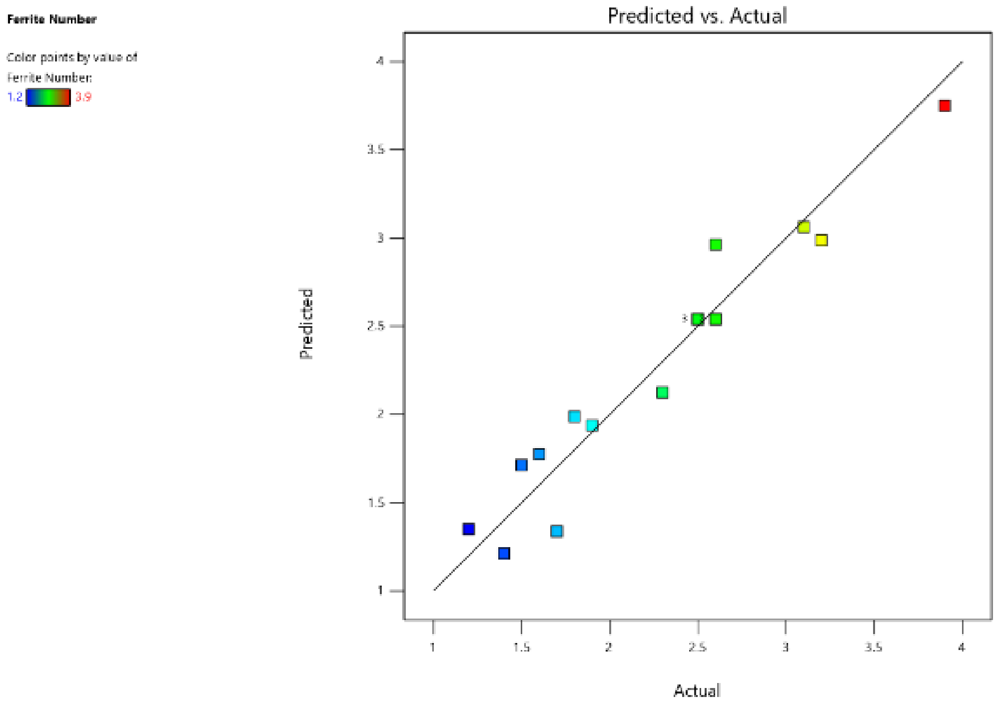

Figure.5 Welding current 100A, welding angle80 D, welding speed 115mm/min

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Result and discussion

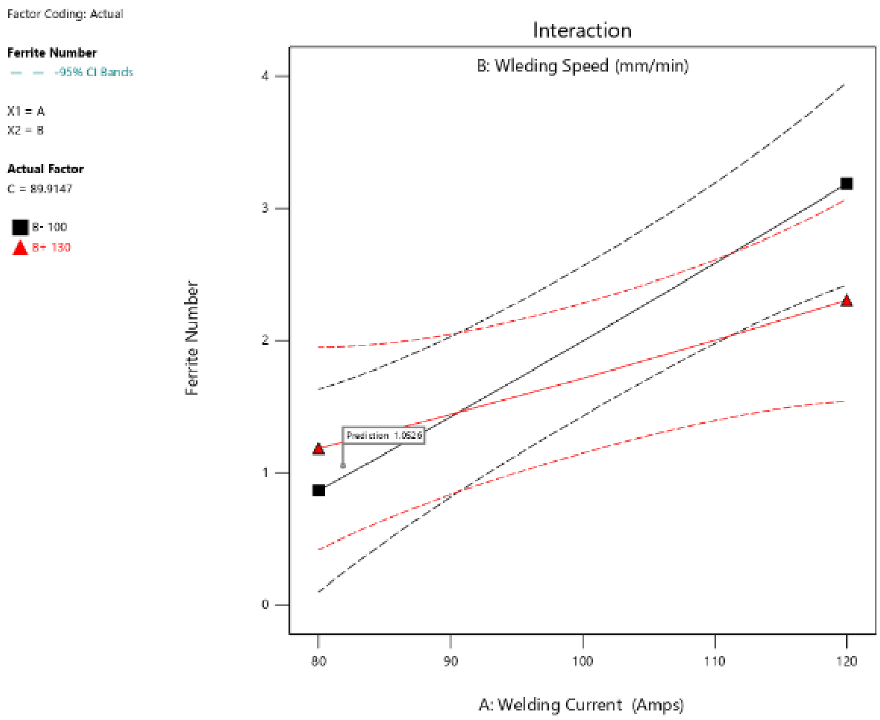

Figure.6 Interaction between Effects of welding current and speed on ferrite number

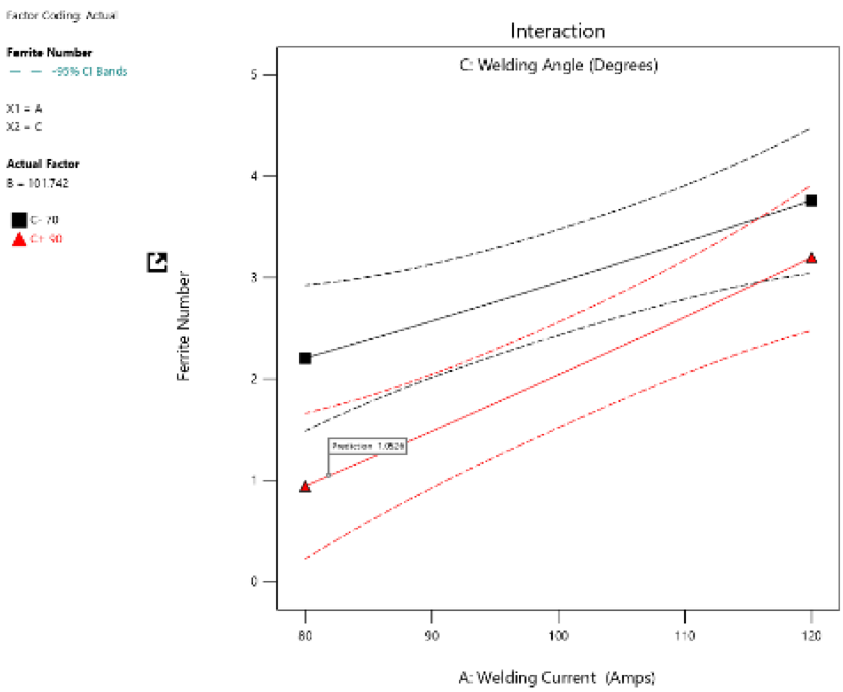

Figure.7 welding angle and Effects of welding current interactions on ferrite number

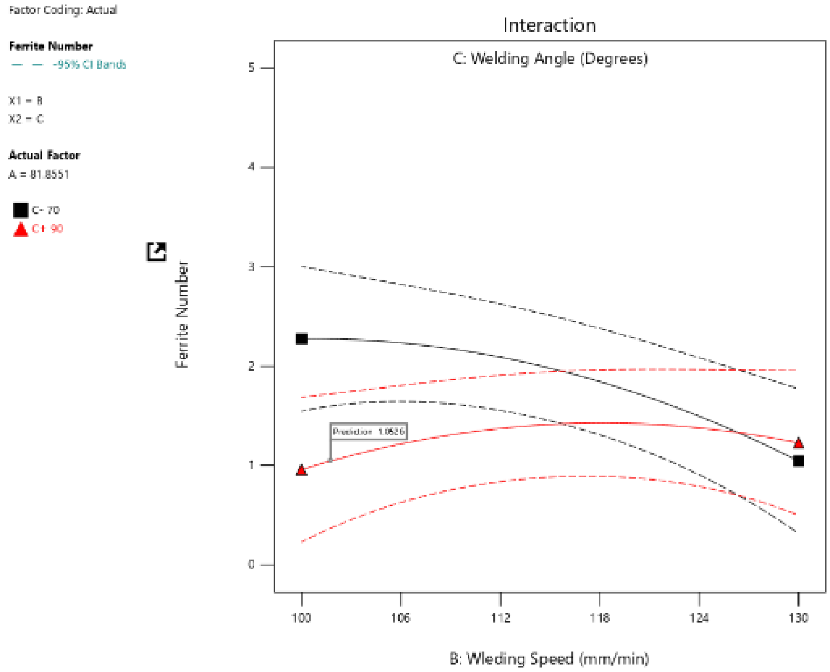

Figure.8 ferrite number is affected by the interaction between welding speed and angle.

Ferrite number and welding speed interaction

It is clear from the data that the ferrite crystals continuously reduce with increasing welding speed; as a result, as welding speed rises, less filler material is deposited, which lowers the ferrite content is shown in fig 7.

Ferrite number and the effect of welding gun angle

A welded connection's ferrite number may be affected. by the welding gun angle. A stainless-steel weld's microstructure's ferrite content can be determined by looking at the weld's ferrite number is shown in fig 8**.**

The effect of welding speed and current on ferrite number

The ferrite number in a welded joint can be significantly affected by the combination of welding current and welding speed. A stainless-steel weld's ferrite number, a gauge of the amount of ferrite in the microstructure, is impacted by a number of welding factors, including welding current and welding speed. In general, a higher welding current tends to raise the weld's ferrite content, whilst a higher welding speed tends to lower it. This is so because welding speed affects the rate of cooling while welding current affects the amount of heat input. Ferrite tends to form more readily when cooling occurs more slowly and with higher heat input than when cooling occurs more quickly and with lower heat input.

Because changes in one parameter can either cancel out or strengthen the effect of changes in the other, the impact on ferrite number of the relationship between welding current and welding speed can be complicated. For instance, raising the welding current may raise the ferrite content while raising the welding speed may lower it. Consequently, considerable thought and trial are needed to establish the appropriate welding current and speed combination to obtain the appropriate ferrite content. It is crucial to keep in mind that additional welding variables, like electrode type, shielding gas

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composition, and preheat temperature, can also affect the amount of ferrite present. Hence, to obtain the desired microstructure and characteristics in a welded joint, a thorough understanding of all welding factors and their interactions is required is shown in fig 9.

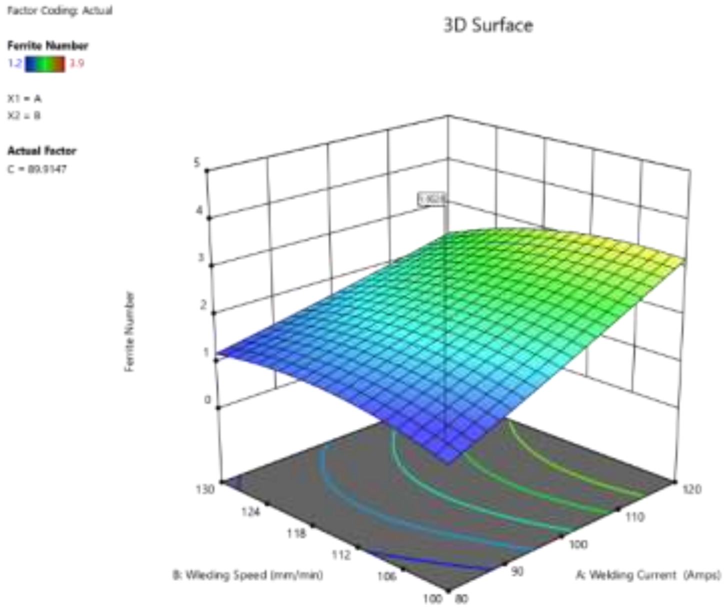

Figure.9 3d graph

The effect of welding gun angle and speed on the number of ferrite during welding

The amount of ferrite in a welded connection can be significantly affected by the interaction between welding gun angle and welding speed. The ferrite number, a measurement of the amount of ferrite in the weld, is influenced by a number of welding parameters, including welding speed and welding gun angle microstructure of a stainless-steel weld. In general, greater welding speeds tend to produce materials with less ferrite, whereas a perpendicular welding gun angle tends to produce materials with more ferrite. This is so because welding gun angle affects the heat input while welding speed impacts the rate of cooling during welding. Faster cooling rates and lower heat input tend to minimize ferrite while slower cooling rates and increased heat input likely to promote ferrite formation**.**

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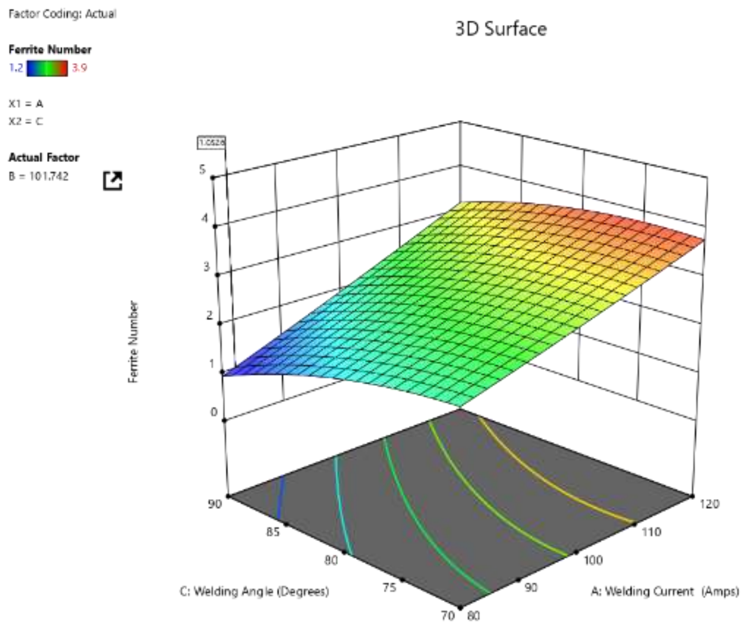

Figure.10 3d graph

Because changes in one parameter can either cancel out or strengthen the effect of changes in the other, the connection between the ferrite quantity and welding gun angle and welding speed can be complicated. For instance, while a perpendicular welding gun angle may enhance ferrite content, increasing welding speed may decrease it. Consequently, considerable thought and trial are needed to determine the ideal welding speed and welding gun angle combination to obtain the appropriate ferrite content. It is crucial to remember that additional welding variables, including welding current, electrode type, the composition of the shielding gas, and the preheat temperature, can also affect the amount of ferrite present. Hence, to obtain the desired microstructure and characteristics in a welded joint, a thorough understanding of all welding factors and how they interact is necessary is shown in fig 10.

Microstructure in the MIG welding of SS 304

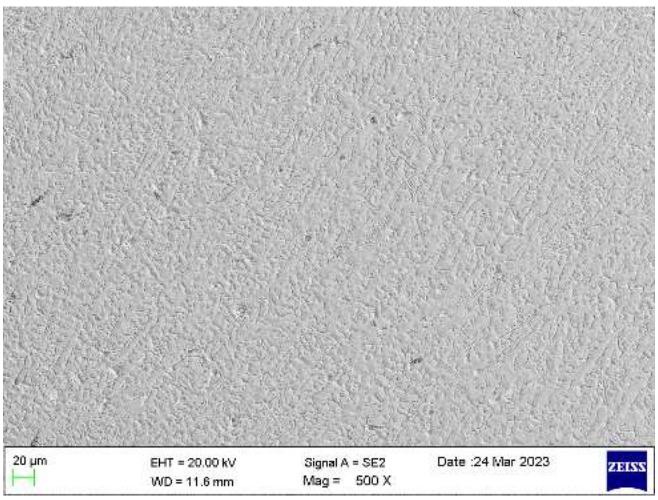

Figure.11 Welding current 100A, welding angle 80D, welding speed 115mm/min

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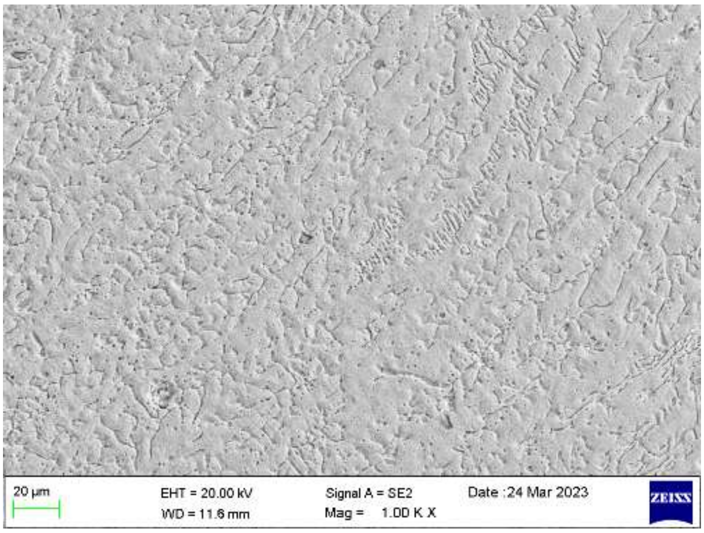

Figure.12 Welding current 120A, welding angle 80D, welding speed 100mm/min

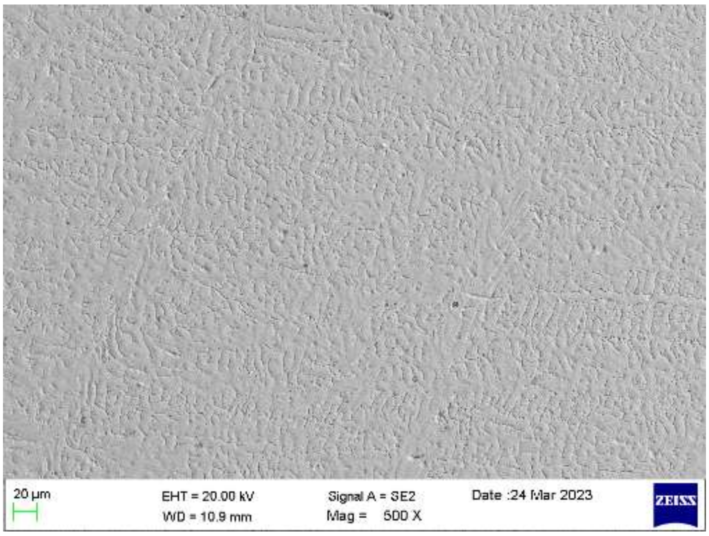

Figure.13 Welding current 100A, welding angle80 D, welding speed 115mm/min

The microstructural modifications made to a welded junction made of 304 stainless steels using the MIG welding method with varying heat inputs. The mechanical characteristics of the welded connection are significantly influenced by the weld's microstructure and the heat-affected zone (HAZ). The welding process parameters, material composition, and heat input are just a few of the factors that affect the microstructure of the weld metal and HAZs. In order to optimize the welding process and produce the necessary mechanical qualities, it is crucial to understand how these elements affect the microstructure. SEM pictures to examine the cross-section of the welded junction at various heat inputs in order to look at the microstructure of the joint. High magnification SEM is an effective instrument for examining the microstructure of materials and can provide information on the distribution, size, and shape of individual grains that are shown in fig 11, 12, 13.

The SEM image reveals that at lower heat inputs, the weld metal's microstructure is made up of uniformly tiny, equiaxed grains, which are indicative of a fine-grained microstructure. Yet, as the heat input rises, the weld metal's grain size expands and the morphology of the grains becomes more elongated. This suggests that the microstructure has become coarser, it can cause the mechanical attributes of the welded connection to decline. Overall, the microstructural research reported in this paper provides significant information on how heat input affects the microstructure of a MIG-welded joint made of AISI 304 stainless steel. In a variety of industries, including aerospace, automotive, and construction, using this knowledge, welding process parameters can be optimized for desired mechanical qualities and the reliability of welded structures.

Conclusion

- The effect of welding parameters on the ferrite number of stainless steel 304 are investigated.
- Response surface methodology (RSM) was used to optimized the welding current, speed and gun angle are for the desired ferrite number.
- The results showed that the ferrite number was mostly affect by the welding current and welding speed, as well as their interaction.
- The optimum combination of welding current and speed was found to be 80 A and 130 mm/s, respectively.
- The welding current and speed increases as ferrite number also increases.
- The welding current and speed decreases as ferrite number also decreases.
- With this combination of the process parameter such as welding current , welding speed and welding gun angle have strong interaction on ferrite number.
- With this work, it is possible control the process parameter to achieved the ferrite number in stainless steel.

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