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Numerical Optimization and Simulation of Molten Metal Viscosity to Control Residual Stress in TIG Mild Steel Welds

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ABSTRACT

Welding researchers have a goal of continuously reducing weld defects to improve on the strength and integrity of fabricated structures. This study is centered on numerical control and optimization of molten metal viscosity and residual stress of mild steel weld, the TIG welding process was used to produce the specimen. The strength of the model was evaluated by certain statistical diagnostics which includes residual plot,predicted versus observed plot,normal probability plot and cooks distance plot which showed satisfactory results, however enabling the model to explain the interaction between the process factors and viscosity, as well as the capacity to control the residual stress.

Keywords: Simulation, Molten Metal Viscosity, Residual Stress, Optimization Tungsten, Weld

1. INTRODUCTION

Welding is a process of joining two or more metal parts together by the application of heat to form one single product, the structure formed possesses optimum strength that is greater than various methods used for metal joining. [1] The welded structures undergo excessive heating and fast cooling that can alter the microstructural configuration and mechanical property of the weld which can introduce residual stress [2]. Residual stress in welded components is as a results of the non-uniform expansion and compression of the weld and the base material caused by the non-uniform heat distribution during the welding process[3]. Most residual stresses that are found in welded components are harmful tensile stress which gives negative a effect to the weldment, some researchers discovered that compressive residual stress are beneficial to weldments. Tensile residual stress may lead to crack initiation to the welding component, while compressive residual stress can improve the component quality. The principal source of welding residual stress are shrinkage, quenching and phase transformation. Tensile residual stress occurs due to the shrinkage while compressive residual stress affected by the quenching and phase transformation process [4]. Both tensile and compressive residual stress exists in welding component, but its distribution depends on location. Welding component can be improved by applying specific treatment to certain location based on the residual stress distribution data. So it is important to identify the welding residual stress distribution to improve its quality and reduce the negative effect to the welded structure. There are many factors that affect the residual stress distribution in weldment components, these includes i. The existence of residual stress before welding (manufacture and fabrication) ii. Material properties (weld and parent metal) iii. The geometry of the joined components iv. Restrain applied v. Welding procedure vi.

Operation after welding [5]. weld bead geometry is an important factor considered in determining the strength of a weld joint, studies have shown that the viscosity of the molten metal has a great influence on the flow rate as well as the bead geometry.[6] New methods for measuring molten materials was developed. In this technique, four steps were done to achieve the results, a small sample of material was levitated and melted in a high vacuum using a high temperature electrostatic levitator, the resonant oscillation of the drop was induced by applying a low level AC electric field pulse at the drop of resonance frequency, the transient signals which followed the pulses were recorded, and both the surface tension and the viscosity were extracted from the signal [7]. An extensive research work on optimization of welding process was done, the authors studied the optimization of different welding processing using statistical and numerical studied the optimization of different welding processing using statistical and numerical approach. The optimization methods covered in their survey were appropriate for modelling, control and optimizing the different welding process [8]. Response surface methodology was applied to study the direct and interaction effects of SAW parameters (open ciruit voltage. wire feed rate, welding speed and nozzle-to-workpiece distance) on the cladding geometry (depth of penetration, height of reinforcement, weld width and dilution %). The process parameters obtained from the developed models were employed to clad 1S2062 Structural Steel plate of 20-mm thickness using 316L stainless steel wire of 3.15 mm diameter. They concluded that a low dilution of 22.57% can be produced by both high voltage and high welding speed or low voltage and low welding speed [9]. RSM models and contour graphs was used to explain the relationship between input parameters namely the open-circuit voltage, wire feed rate, welding speed and nozzle-to-plate distance to some responses namely, the penetration, reinforcement, width and percentage dilution of the weld bead in SAW of pipes. They demonstrated that all responses decrease with increasing welding speed. Also, when the nozzle-to-plate distance increases all responses decrease, but reinforcement increases. Moreover an increase in the wire feed rate results in an increase in all responses but the width remains unchanged. [10]

2. RESEARCH METHODOLOGY

In this study the response surface methodology was employed to optimize the weld molten metal viscosity and residual stress. The Tungsten inert Gas welding process was used to produce the weld samples of mild steel plates. Argon gas was used as shielding gas to protect the weld pool from atmospheric interaction.

2.1 Material selection

Mild steel is selected materials because of its affordability and availability. Mild steel material is mostly applied in engineering structures because of its attractive properties. This grade has high corrosion resistance and can be operated at elevated temperature. The work piece has the following Dimensions of specimen: 60mmx40mmx10 mm

2.2 *Welding Process Parameters*

The welding process parameters consists of current, voltage, gas flow rate, their range of values are shown in table 1.

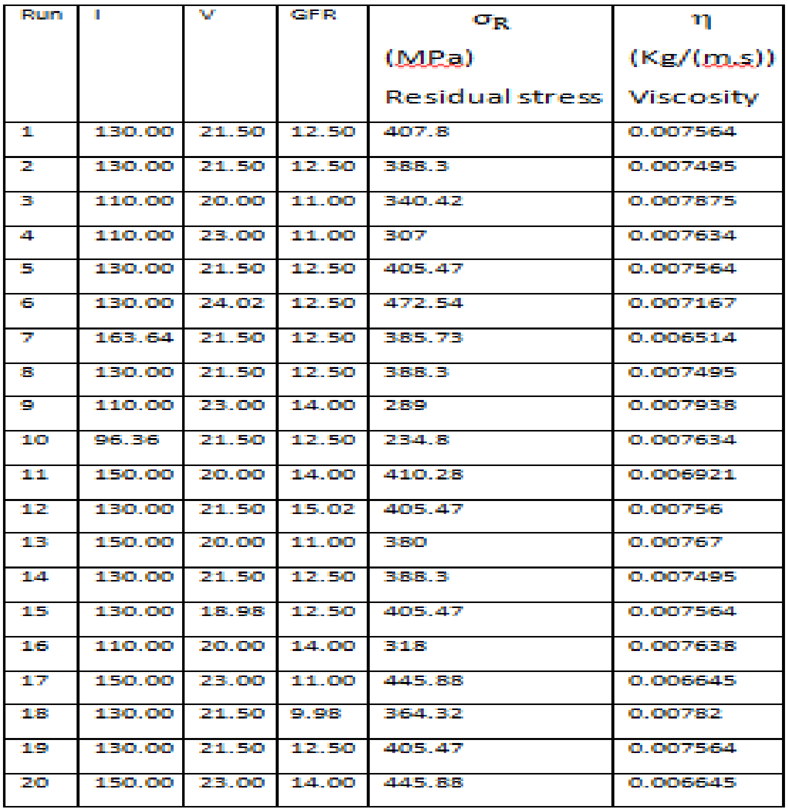
Table 1: process parameters

Factors	**Unit**	**Symbol**	**Low (-1)**	**High (+1)**
Welding Current	Ampere	I	130	170
Welding Voltage	Volts	V	20	24
Gas Flow Rate	Lit/min	GFR	13	17

2.3 Conducting the experiments using the design matrix

In the present work, mild steel plates of 10mm thickness and 60 mm lengths were butt joined using the desired filler rod at varying levels of current voltage and gas flow rate t by manual TIG welding process. This three parameters were taken as variable for present study and their three levels were chosen for which responses were measured, and the central composite design was selected as the experimental design method. These parameters with their levels are shown in table 1 .Before welding all, plates were cleaned chemically by acetone in order to remove any source of contaminants like rust, dust, oil etc. Single pass welding was performed on the samples under the conditions mentioned below.: Electrode type: 98% tungsten, 2% thoriated Shielded gas type: pure argon Electrode diameter.: 2.4 mm Current type: DCEN .The experimental results are shown in table 2

Table 2: Experimental data



Run	I	V	GFR	σ_R (MPa) Residual stress	η (Kg/(m.s)) Viscosity
1	130.00	21.50	12.50	407.8	0.007564
2	130.00	21.50	12.50	388.3	0.007495
3	110.00	20.00	11.00	340.42	0.007875
4	110.00	23.00	11.00	307	0.007634
5	130.00	21.50	12.50	405.47	0.007564
6	130.00	24.02	12.50	472.54	0.007167
7	163.64	21.50	12.50	385.73	0.006514
8	130.00	21.50	12.50	388.3	0.007495
9	110.00	23.00	14.00	289	0.007938
10	96.36	21.50	12.50	234.8	0.007634
11	150.00	20.00	14.00	410.28	0.006921
12	130.00	21.50	15.02	405.47	0.00756
13	150.00	20.00	11.00	380	0.00767
14	130.00	21.50	12.50	388.3	0.007495
15	130.00	18.98	12.50	405.47	0.007564
16	110.00	20.00	14.00	318	0.007638
17	150.00	23.00	11.00	445.88	0.006645
18	130.00	21.50	9.98	364.32	0.00782
19	130.00	21.50	12.50	405.47	0.007564
20	150.00	23.00	14.00	445.88	0.006645

3. RESULTS AND DISCUSSION

To develop an optimization model the goodness of fit is used to check for the strength of the model, the quadratic model was observed to a high strength to explain the interaction between the molten metal viscosity and residual stress as shown in table 3

Table 3: goodness of fit statistics for viscosity

Std. Dev.	**5.701E-005**	**R-Squared**	**0.9901**
Mean	7.420E-003	Adj R-Squared	0.9812
C.V. %	0.77	Pred R-Squared	0.9358
PRESS	2.114E-007	Adeq Precision	37.308

The quadratic model was observed to a high strength to explain the interaction between the residual stress and molten metal viscosity as shown in table 4

Table 4:goodness of fit statistics for residual stress

Std. Dev.	**15.95**	**R-Squared**	**0.9590**
Mean	379.42	Adj R-Squared	0.9221
C.V. %	4.20	Pred R-Squared	0.7334
PRESS	16560.39	Adeq Precision	21.418

To check for outliers in the data used to develop the model, a residual plot is required, which must cluster along the line inclined at angle 45 degrees which is shown in figure 1.

To diagnose the statistical properties of the response surface model, the normal probability plot of residual presented in Figure 2.

In order to detect a value or group of values that are not easily detected by the model, the predicted values are plotted against the actual values, for viscosity which is shown in the figure 3.

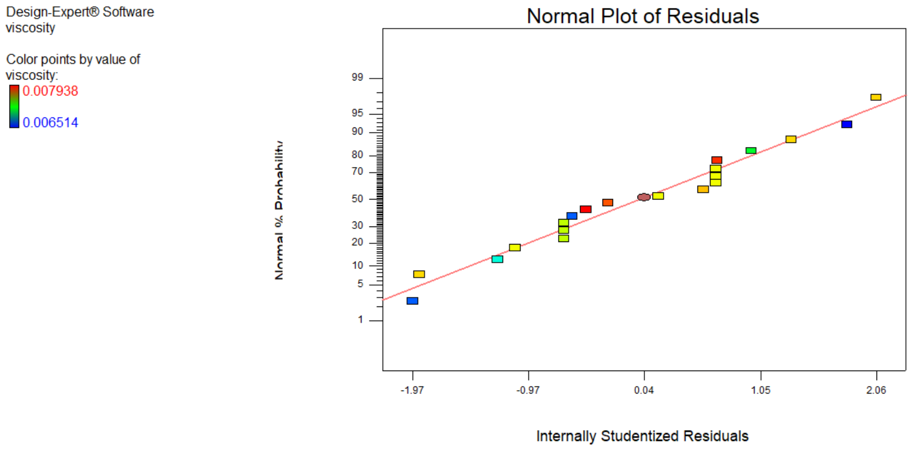


Figure 1: Normal plot of residuals for viscosity

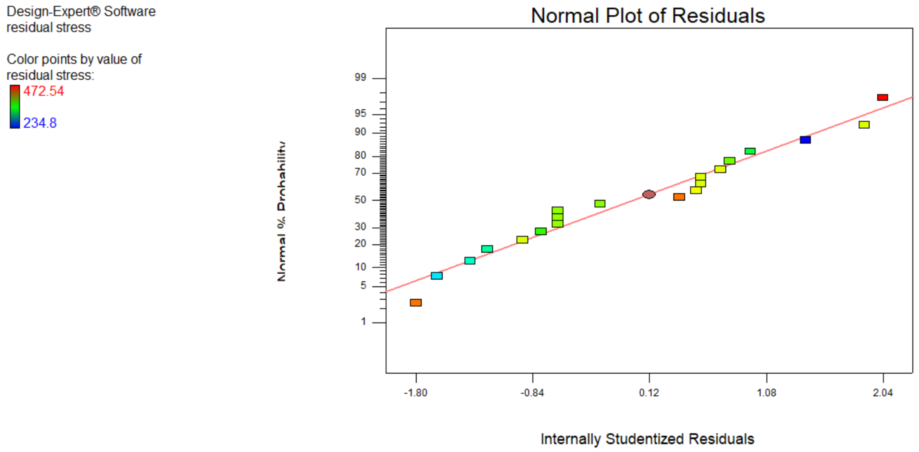


Figure 2: Normal plot of residuals for residual stress

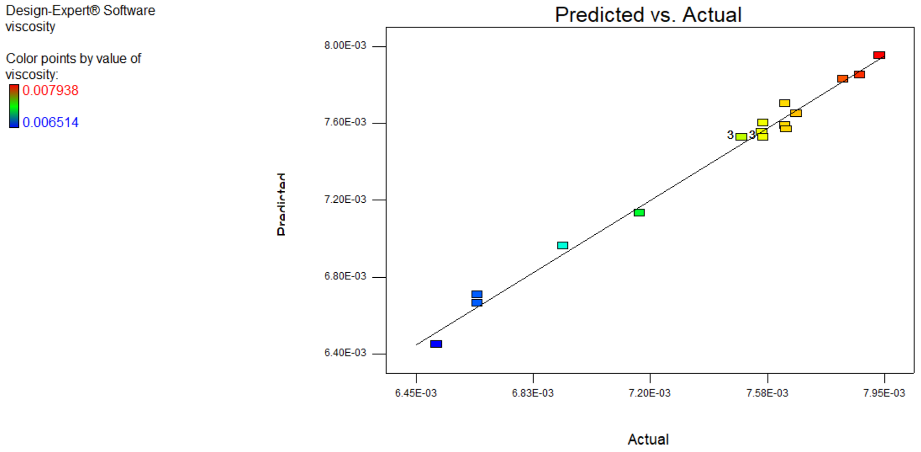


Figure 3: Plot of Predicted Vs Actual for viscosity

In order to detect a value or group of values that are not easily detected by the model, the predicted values is plotted against the actual values, for residual stress which is shown in the figure 4.

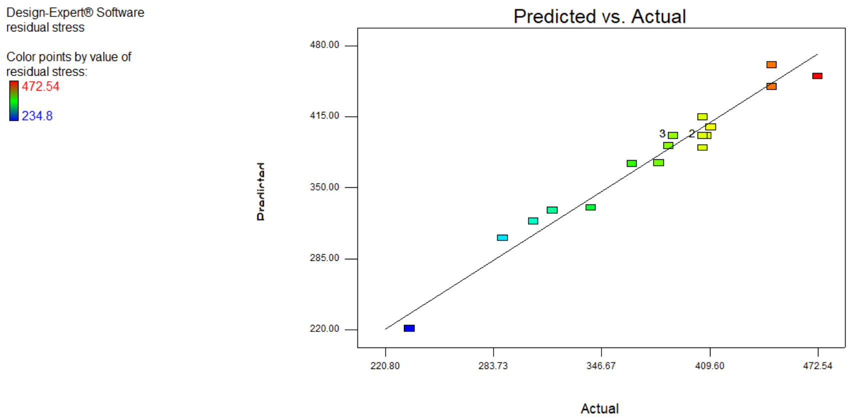


Figure 4: Plot of Predicted Vs Actual for residual stress

The generated cook's distance for the viscosity is presented in Figures 5

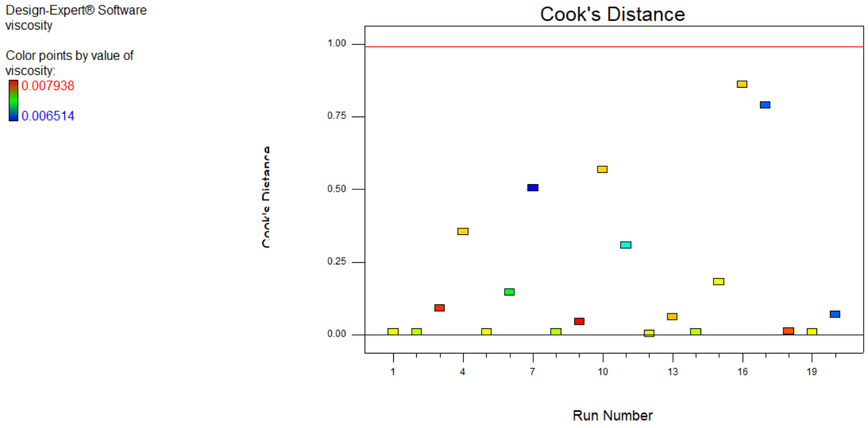


Figure 5: Generated cook's distance for viscosity

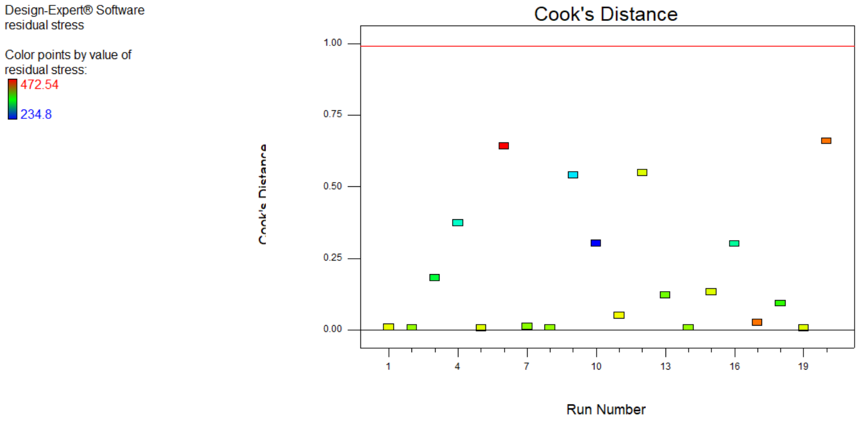


Figure 6: Generated cook's distance for residual stress

To determine the presence of a possible outlier in the experimental data, the cook's distance plot was generated for the different responses. The cook's distance is a measure of how much the regression would change if the outlier is omitted from the analysis. A point that has a very high distance value relative to the other points may be an outlier and should be investigated. The generated cook's distance for the residual stress is presented in Figures 6

The numerical optimal solution was determined for the residual stress and the molten metal viscosity which is shown in table 5.

Table 5 : The numerical optimal solution

Number	Current	voltage	gas flow rate	residual stress	Viscosity	Desirability
1	110.00	21.38	11.00	313.512	0.00778952	0.824
2	110.00	21.50	11.00	312.913	0.00777898	0.824
3	110.03	21.22	11.00	314.687	0.00780179	0.823
4	110.00	21.61	11.00	312.546	0.00776914	0.823
5	110.00	21.35	11.02	313.721	0.00779009	0.823
6	110.00	21.32	11.02	313.959	0.00779222	0.823
7	110.00	20.95	11.00	316.841	0.00781926	0.822
8	110.00	20.77	11.00	318.932	0.0078294	0.819
9	110.00	20.70	11.00	319.789	0.00783267	0.818
10	110.00	20.29	11.00	326.128	0.00784758	0.808
11	110.00	20.77	11.17	319.937	0.00780994	0.807
12	110.00	20.02	11.00	331.233	0.00785263	0.798
13	110.00	22.75	11.00	316.64	0.00762966	0.795
14	110.00	21.65	11.60	314.634	0.00774297	0.793
15	110.00	22.73	14.00	302.079	0.00793753	0.790

Table 5 shows the numerical optimal solutions that can control the residual stress within this range of process parameters,the results shows that current of 110,voltage of 21.38,gas flow rate 11 wil produce minimum residual stress of 313.5 and viscosity of 0.0007.

The contour plots showing viscosity variable against the optimized value of current and voltage is presented in Figure 7.

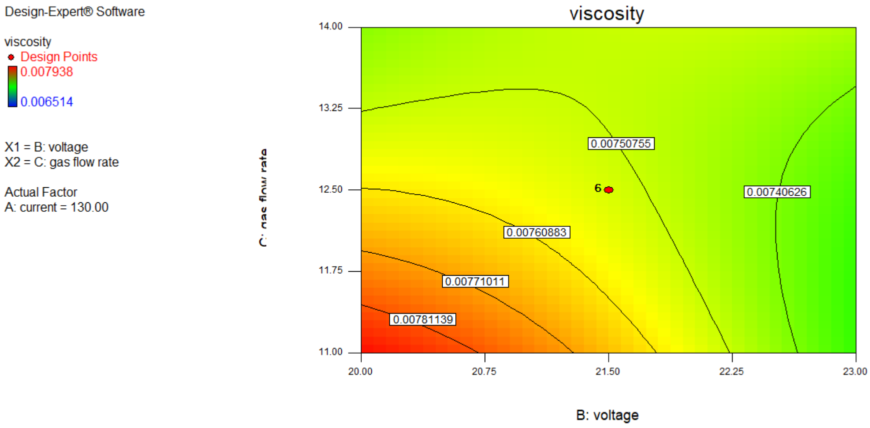


Figure 7: Predicting viscosity using contour plot

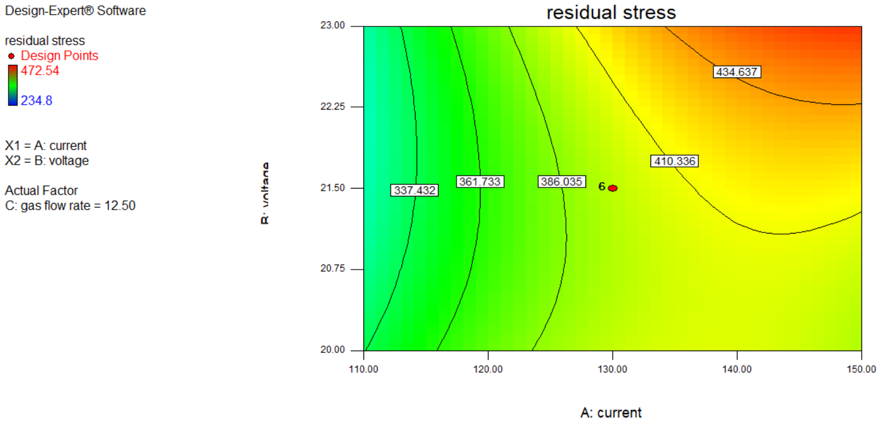


Figure 8: Predicting residual stress using contour plot

The contour plots showing residual stress response variable against the optimized value of current and voltage is presented in Figure 8

3.2 DISCUSSION

The study is centered on numerical control and optimization of molten metal viscosity and residual stress that exist in TIG welding of mild steel. The RSM technique was used to carry out the simulation and optimisation.To develop an optimization model the goodness of fit is used to check for the strength of the model and the quadratic model possessed adequate strength to explain the interaction between the molten metal viscosity and residual stress as shown in table 3 and 4. Outliers are unwanted irregularities observed in a data set which can be put on check with the following plots. such as residual plot,predicted versus observed plot,normal probability plot and cooks distance plot as shown in figure 1,2,3,4,5 and 6 the results of these plots shows no outlier present. Results in Table 5 shows the numerical optimal solutions that can control the residual stress within this range of process parameters,as a combination current of 110amp,voltage of 21.38 volt,gas flow rate 11lit/min wil produce a weld with minimum residual stress of 313.5 and viscosity of 0.0007.

4. CONCLUSION

In this study a numerical optimal model to control molten metal viscosity and residual stress in tungsten inert gas welding of mild steel has been achieved. This study reveals that current has strong influence on the viscosity and residual stress responses. The strength of the model was evaluated by certain statistical diagnostics which showed satisfactory results, however enabling the model to explain the interaction between the process factors and viscosity, as well as the capacity to control the residual stress.

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