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Optimum Evaluation of Stokes Number Influencing TIG Molten Metal Flow Pattern

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ABSTRACT*-Welding researchers have a responsibility of improving the integrity and strength of welded structures , the Fluid flow of the molten metal has a major effect on energy transport from the weld pool to the surrounding material, which in turn affects the geometry .Additionally, the flow motion and its volatilities determines the material properties and quality of the weld. . This study was carried out with the aim of optimizing and predicting the dimensionless parameters characterizing molten metal flow patterns of mild steel weld pool* **,** *with a purpose of developing models to explain the relationship between this dimensionless numbers and the flow pattern. A 30 run central composite design matrix was generated which guided in performing the experiments,the stokes dimensionless number was computed and recorded for each specimen .Thereafter the Response surface method expert system was employed to analyse the data collected from the experiment.In this study the second order polynomial model was adopted having current, voltage, gas flow rate and welding speed as input factors while the stokes dimensionless numbers is the target response. The result obtained possessed adequate strength to predict the targeted response.RSM model produced numerical optimal solutions having a combination of current 189.85A ,voltage 18.00v wire diameter 1.61mmand wire feed rate of 25mm/min to produce a welded joint withwith Stokes number of 7005.6, at a desirability value of 71.8%..In this study an approach using the response surface methodology for optimizing and predicting weld process parameters in order to enhance the integrity of welded joints has been successfully introduced and its effectiveness and efficiency well demonstrated.*

KEYWORDS:*weld pool, stokes number,response surface methodology,fluid flow*

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I. Introduction

Fluid flow has a major effect on energy transport in a welding process, which determines the geometry of the weld metal and the metallurgical configuration of the heat-affected zone. Additionally, the flow motion and its volatilities determines the material properties and quality of the weld. A number of mathematical models have been established, based on laminar[5] or turbulent [6] flow, in order to describe fluid motion and its effects on heat transfer phenomena and ultimately the mechanical properties of the weld produced.

many models have provided important physical insights into the mechanisms of weld pool development, it is still unclear whether the flow is laminar or turbulent. However, for numerical simulations it is necessary to choose a suitable model, laminar models or turbulent models could lead to significantly different results. In most cases, laminar flow has been assumed in the weld pool models, but this is questionable for two reasons: Firstly, the predicted weld pool depths are significantly larger than the measured penetration for comparable welding conditions, as reported[7]whereas both of their turbulent models show better agreement. Secondly, visual observations of weld pools indicate unsteady, chaotic behaviour, which makes it associated with the transition to turbulence [7]. Thus both models and visual observations suggest that the flow in weld pools may not be fully laminar.

The concept of modeling fluid motion in weld pools was first proposed [1], but the first comprehensive treatment of the problem, with allowance for both heat transfer and mass. A recent development has provided a coupling between the behavior of the welding arc and the weld pool [2] by predicting, rather than postulating, the heat and current fluxes falling on the free surface of the weld pool. Up to the present, relatively little work has been done to provide a direct, systematic comparison of the experimentally measured and the theoretically predicted weld pool shapes, although there is some evidence that the current weld pool modeling efforts appear to be "on the right track." It is stressed that laminar flow has been explicitly assumed in all the weld pool modeling efforts up to the present. There appears to be some evidence, that the velocity fields in weld pools may not be fully laminar, but would approach mildly turbulent or at least transitional flow. Visual observation of weld pools indicates unsteady, chaotic behavior that one would associate with the transition to turbulence. There is no known direct measurement of turbulent velocity fluctuations in weld pools other than visual observation. The reason is that it is extremely difficult to directly measure such velocity fluctuations in a small (- 5-mm radius) highly heated pool under the influence of a welding arc. However, some elementary calculations [3] had supported the concept that the pool circulation could be turbulent. On a more fundamental basis, the very high shear rates that one could as-sociate with free surface velocities of the order of 0.5 to 1.0 m/s could well lead to instabilities and, hence, to the onset of turbulent fluctuations. Two additional semiquantitative points may be made at this stage. One of these is that the general weld pool shapes observed in practice tend to be quite rounded [kou], which would indicate turbulent, rather than laminar flow behavior, which has strong directionality in the flow field. The other is that the apparent insensitivity of many welding operations to changes in certain input parameters can well be explained by the "leveling effect" of turbulence, which will tend to provide a more uni-form temperature field in the system. If weld pools were turbulent, or at least in the transitional regime, this would have far reaching implications regarding the current modeling efforts aimed at representing weld pool behavior. Simply put, if the flow were turbulent, the effective viscosity and thermal conductivity would be significantly higher, giving a markedly different weld pool shape and significantly different mode of heat and momentum transfer within the pool itself. Indeed, many of the conclusions based on the laminar fluid flow analysis may have to be revised. In the following, we shall present some highlights of the mathematical formulation of the problem, together with some computed results, that should pro-vide a first attempt at this important and rather novel problem.

II. Research Methodology

2.1.Design of experiment

For optimal experimentation process a design of experiment is required. The design expert software was employed for this task. A particular experimental design matrix is selected based on its capacity to handle certain number of input process parameters and the central composite has been known as one of the best experimental matrix and was chosen for this study. The process parameters considered in this study are current, voltage,wire diameter, wire feed rate and the stokes number.

2.2 Method of Data Collection

The central composite design matrix was developed using the design expert software, producing 30 experimental runs. The input parameters and output parameters make up the experimental matrix and the responses recorded from the weld samples was used as the data.

2.3. preparation of weld specimen

150 pieces of mild steel coupons measuring 60 mmx 40 mmx10 mm was used for the experiments, the experiment was performed 30 times ,using 5 specimen for each run. The mild steel coupons were bevelled and machined ,thereafter the tungsten inert gas welding equipment was used to weld the plates using 100% pure Argon gas to protect the weld specimen from atmospheric interaction.

III. Resuslts And Discussion

To accept any model, its satisfactoriness must first be checked by an appropriate statistical analysis output. The normal probability plot of residual ,predicted versus actual plot,cookes distance for the stokes number presented in Figure 3.1,3.2 and 3.3

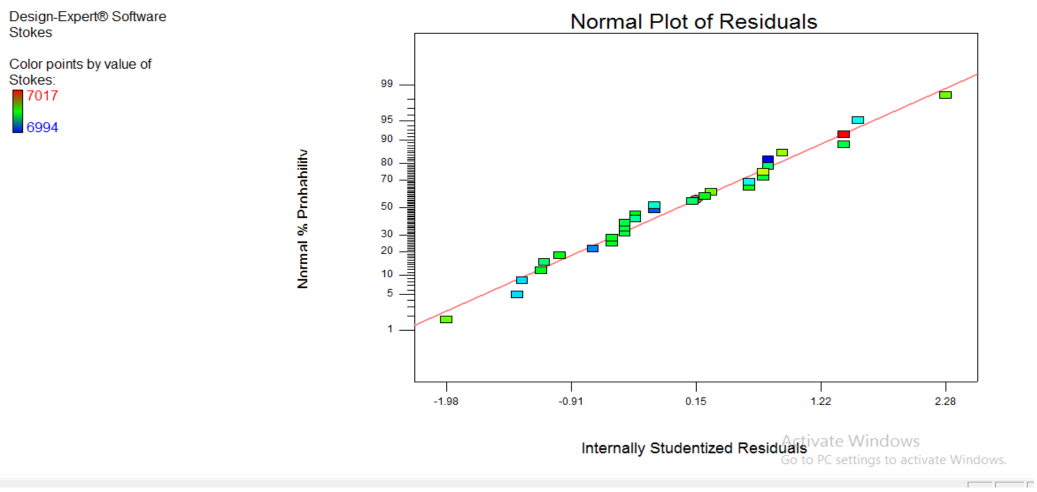

Figure 3.1: Normal probability plot of studentized residuals for stokes number

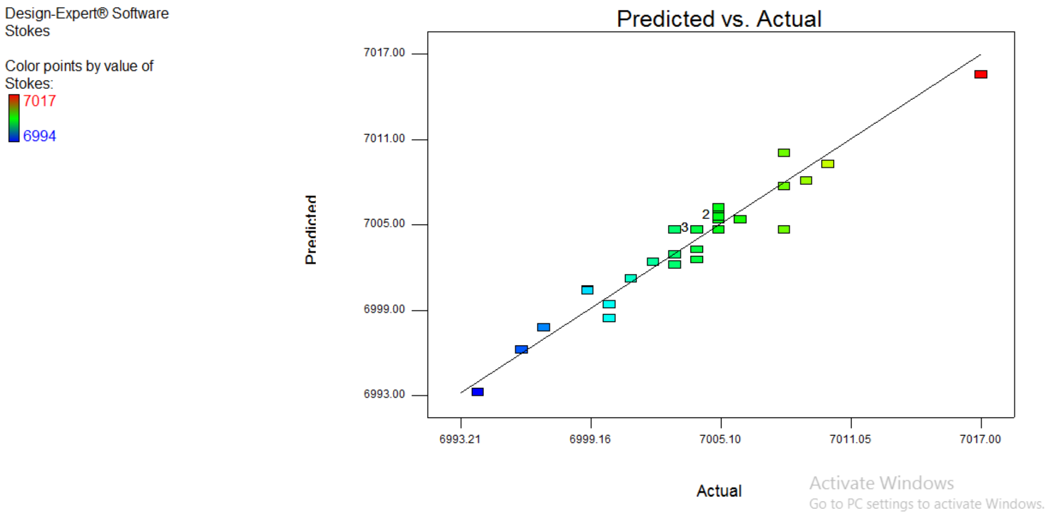

Figure 3.2: Plot of Predicted Vs Actual for the stokes number response

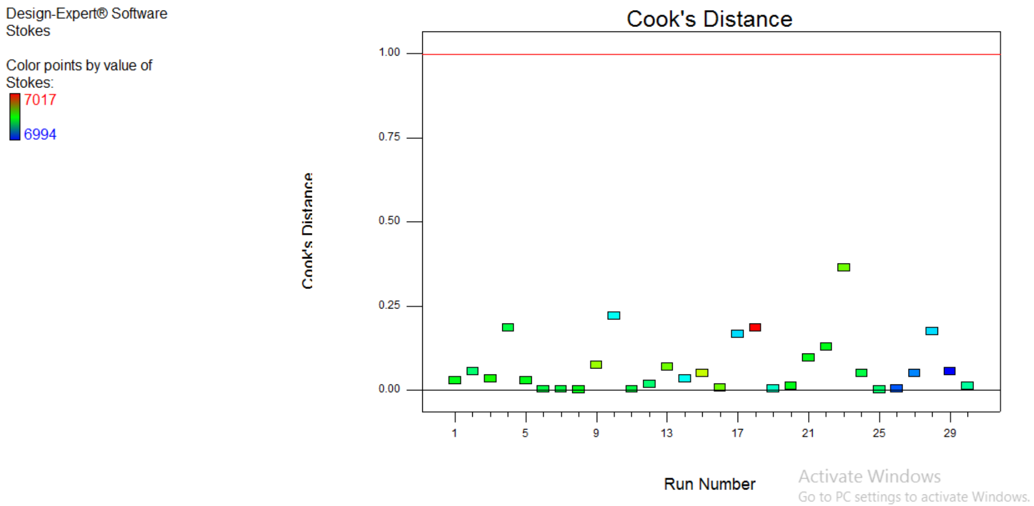

Figure 3.3: Generated cook's distance for stokes number

It can be observed that the points follow a straight line despite the slight scatter. There is no defined pattern like an "s-shaped" curve aside the linear trend.This indicates that the residuals are normally distributed and no transformation of the response data is required for better analysis. The normal probability plot of studentized residuals was employed to assess the normality of the calculated residuals. The normal probability plot of residuals which is the number of standard deviation of actual values based on the predicted values was employed to ascertain if the residuals (observed – predicted) follows a normal distribution. It is the most significant assumption for checking the sufficiency of a statistical model. Result revealed that the computed residuals are approximately normally distributed an indication that the model developed is satisfactory. 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,To determine the presence of a possible outlier in the experimental data, the cook's distance plot was generated for the stokes response. This measures 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 stokes number shows that the model is satisfactory. To examine the combined effects of the input process parameters on the stokes number and possibly predict and optimize the stokes number and flowability of the molten metal surface plots and contour plots are shown in figure 3.4, 3.5, 3.6, 3.7 and 3.8.

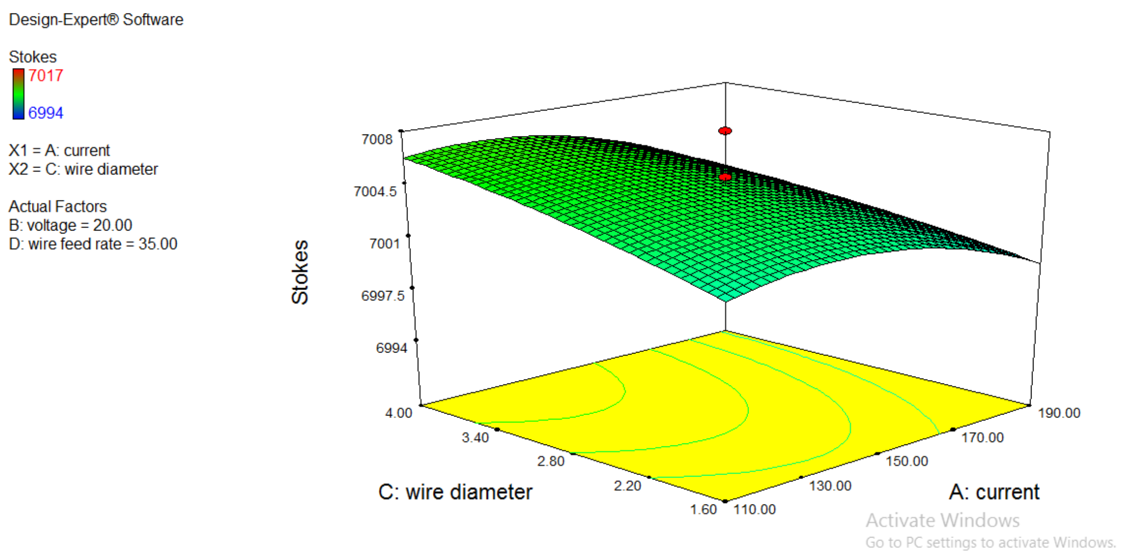

Figure 3.4: Effect of current and wire diameter on stoke number

To study the effects of wire feed rate and current on the stokes number, 3D surface plots presented in Figure 4.54 was generated as follows:

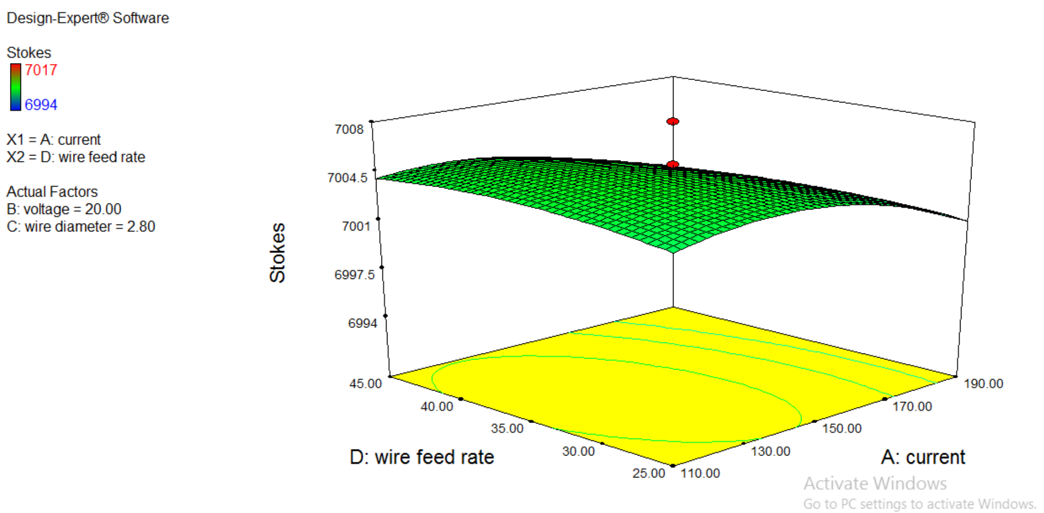

Figure 3.5: Effect of wire feed rate and current on stokes number

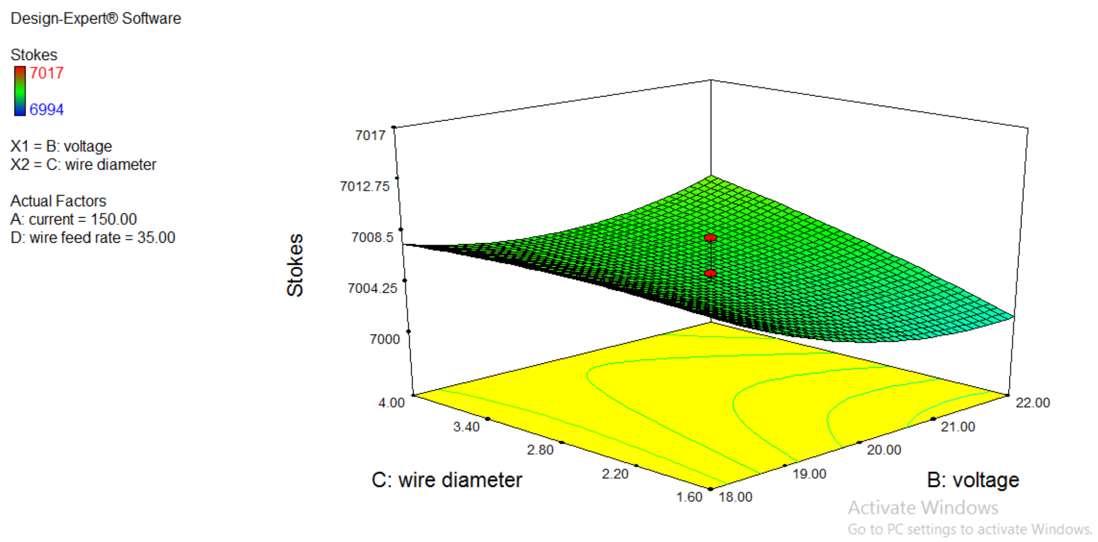

Figure 3.6: Effect of voltage and wire diameter on stokes number

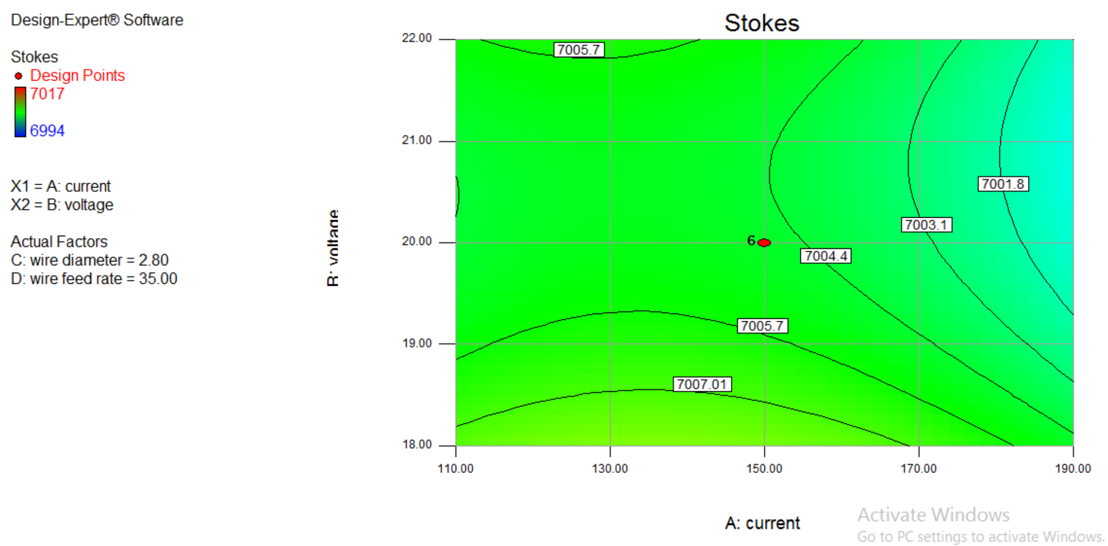

Figure 3.7: contour plot of current and voltage predicting stokes number

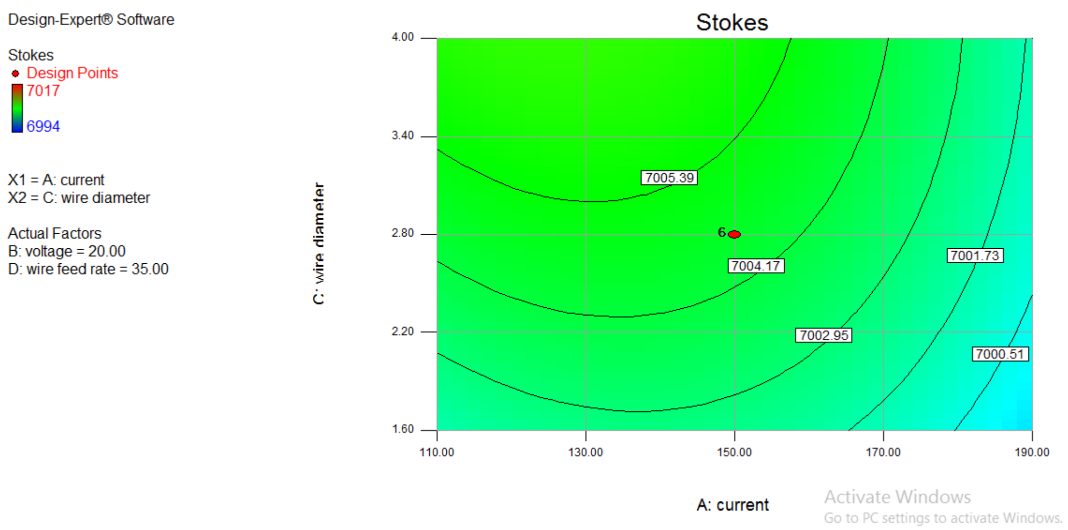

Figure 3.8: contour plot of current and wire diameter predicting stokes number

The optimum value of the stokes number that will produce the best molten metal flow is shown in table 3.1

Current	voltage	wire diameter	wire feed rate	Stokes	Desirability	
189.85	18.00	1.61	25.00	7005.6	0.718	Selected
189.36	18.00	1.60	25.09	7005.65	0.718	
190.00	18.07	1.60	25.00	7005.29	0.716	
189.83	18.00	1.61	25.20	7005.61	0.716	
187.01	18.00	1.60	25.00	7005.89	0.715	
189.99	18.00	1.65	25.00	7005.62	0.714	

IV. Conclusion

The results obtained in this study shows that the higher the stokes number the better the flow pattern of the weld metal. Figures 3.4,3.5 and 3.6 shows the surface plots of current,wire feed rate ,wire diameter and stokes number,it explains the combined interaction between two input parameters and the stokes response. Figure 3.4 shows the best interaction that will amount to a high stokes number. The combined effect of current and wire diameter on stoke number will result in a better flow pattern of the molten metal. Table 3.1 shows the optimum value for stokes number,that is a combination of current(189.85amp)voltage(18.00) wire diameter(1.61) and wire feed rate (25.00) wiil produce a maximum stokes number of 7005.6 which translates into an excellent flowability of the molten metal. The model developed shows adequate strength,suitability and significance .

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