Experimental Investigation of Gas Flow Rate Effect on Mild Steel Plates for Weld Porosity Prevention at GTAW Process using Interactive Factor Plots

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ABSTRACT

The optimization of gas flow rate , using Models, was used to obtain optimized values of other input process parameters for preventing porosity defect at Gas Tungsten Arc Welding (GTAW) process. Interactive factor plots (IFP) were used to show the main effects of importance and interactive effect that affect the model most with a reference line drawn on the interaction plot indicating any effect that exceeds the line as a potential important effect to the model. Interactions occur when the level of a factor is dependent on the effect of a factor. using equations to obtain values of percentage dilution (%D), the values were greatly impacted by the interaction of gas flow rate which has been cross referenced by standard error and produced optimal outcome .In this study, Gas flow rate was dependent upon percentage dilution (solidification rate) of a weld pool, Gas flow rate protects the weld pool from contamination which can cause porosity in welds,Hence,this study is aimed at optimizing gas flow rate in order to establish a correct shielding gas flow rate that will be designed to provide the most efficient gas coverage and prevent gas wastage and in turn improve weld quality and prevent porosity.

Interactive Factor Plots (IFP)of gas flow rate and the main effects of gas flow rate,, showed the optimum values of gas flow rate to be 16 lit/min at a minimized percentage dilution value of 45.95% which was established in this study.

Key words – *Gas Tungsten Arc welding (GTAW), Gas flow rate (F), porosity defect, percentage dilution (%D) interactive factor plots (IFP).*

1. INTRODUCTION

Porosity defect in welds appear due to gas pocket presence in the welded base metal, which results in small holes in the welded joint produced and this could lead to design failure and weld rejection after visually inspecting the welds produced. Porosity welds do not meet standards in non destructive testing (NDT) exercises. To achieve a porosity free welded joint, a percentage dilution quantity that is defined, that will provide sufficient dilution for a controlled solidification of molten metal during welding operation, is required.

Arc welding process like GTAW offers a wide spectrum for steady gas flow, protects the weld pool from contamination that may lead to porosity defect, produces a good arc start, good control of bead contour and produces a good weld penetration area. Some of the root causes of weld porosity are, ineffective weld pool, gas escape during welding and drastic increases in speed due to a super rapid cooling rate. There is a need to optimize the gas flow rate in a systematic way in order to achieve the response: percentage dilution (%D), by using the interactive factor plot model to determine the performance measures. Hence, the basis for this research.

2. EXPERIMENTAL DETAILS

Data was efficiently analyzed using the interactive factor plots and conclusions were meaningfully drawn from the analysis. The aim of the analyses is to show the statistical significance of a main effect (Gas flow rate) on the response (percentage dilution) of interest and the optimum setting for the different factors that affect the response was also determined.

3. MAIN EFFECT (GAS FLOW RATE)

Main effect (gas flow rate) showed a change in the level of factor produced by the change in the average response :percentage dilution (%D) of the factor. An Interactive reference line was drawn and used to analyze the effect of gas flow rate (F) and percentage dilution (% D). The line drawn horizontally, indicated that there is no presence of main effect. In the same way, each level of the factor affects the response (percentage dilution), hence the mean level of the response (percentage dilution) is the same with all the factor levels.

When the line is not drawn horizontally, then, the main effect is present, indicating that different levels of the factor (Gas flow rate) affect the response (percentage dilution). The magnitude of the main effect is great when the slope is steep.

4. INTERACTION EFFECTS

Interactions between gas flow rate and other factors showed the factor, gas flow rate, is at different levels of interaction with other factors and the effect of one factor is different from the effect of the other. A first order is an interaction with two factors (gas flow rate and any other factor)

5. MATERIALS

The material used is a 10mm thick mild steel plate (low carbon) measuring 150mm by 100mm by 10mm as shown in figure 1.

A single flow tube meter attached to a 100% argon shielding gas cylinder was used to record the gas flow rate(F) and records were taken as shown in Table 1.

Figure 1: Mild steel plates

6 . EXPERIMENTAL PROCEDURE

The experiment was carried out with four factors at two levels each as presented in Table 1.

TABLE 1: FACTORS (INPUT PROCESS PARAMETERS) AND THEIR LEVELS

S/n	Input process parameters	Unit	Symbol	Levels	
1	A –welding current	Amp	I	130	190
2	B –welding voltage	Volts	V	15	19
3	C –welding speed	mm/min	S	80	120
4	D –shielding gas flow rate	Lit/min	F	14	18

TABLE 2: RESPONSES

Responses	Unit	Symbol	Range
Percentage dilution	%	%D	40% - 47% Goal: minimization
Heat Input	KJ/min	H.I.R	18KJ/min – 22KJ/min Goal: maximization

Figure 2: Single tube flow meter

The single flow tube meter is used for measuring the gas flow rate. A 100% Argon gas, is the shielding gas used to protect the weld pool from contamination from air which can lead to the presence of gas pockets in the welds and this leads to weld porosity. The profile projector was used to trace and record the weld bead profile such as reinforcement area and weld penetration area. Planimeter readings recorded the weld penetration area as well as the reinforcement area. Percentage dilution results for reinforcement area were measurements taken from the profile projector and the digital planimeter readings were recorded as presented in Table 3.

TABLE 3: REINFORCEMENT, PERCENTAGE DILUTION AND WELD PENETRATION AREA

s/n	Reinforcement area (RA) (mm^2)	Weld penetration area (WP_A) (mm^2)	Total weldment area (TW_A) (mm^2)	Percentage dilution (%D)(calculated)
1	24.75	20.85	45.60	45.70
2	25.00	21.40	46.40	46.09
3	24.03	20.57	46.60	46.08
4	25.40	21.19	46.00	44.93
5	24.40	20.48	44.40	46.08
6	23.65	20.34	44.20	46.06
7	26.51	22.59	49.10	46.03
8	27.95	20.45	44.40	46.04
9	24.55	20.54	45.00	45.66
10	24.80	21.60	45.80	45.86
11	25.33	21.64	47.00	45.00
12	25.25	20.65	45.90	44.95
13	23.92	20.38	44.30	45.99
14	24.05	20.35	44.40	45.81
15	26.60	21.70	48.30	44.91
16	23.29	20.51	44.80	45.88

Percentage dilution was calculated using the following equations,

$$\%D = \frac{WP_A\left(mm^2\right)}{R_A\left(mm^2\right) + WP_A\left(mm^2\right)} \times 100\% \quad (1)$$

Where : WP_A = weld penetration area (mm^2)
RA = Reinforcement area (mm^2)
$TW_A = R_A + WP_A$ = [Reinforcement area + weld penetration area] (2)

7. PRESENTATION OF RESULTS,DISCUSSIONS AND FINDINGS.

TABLE 4: ANALYSIS OF VARIANCE (ANOVA) FOR PERCENTAGE DILUTION (%D)

Input Process parameters	Designation	df	Adj SS	Adj MS	F-value	P-value
Welding current	I	1	3.1863	3.1863	29.57	0
Welding voltage	V	1	0.0839	0.0839	0.78	0.392
Welding speed	S	1	0.0995	0.0995	0.92	0.353
Gas flow rate	F	1	0.0756	0.0756	0.7	0.416
2 way/interaction						
Welding current *welding voltage	IV	1	0.0005	0.0005	0	0.947
Welding current *welding speed	IS	1	0.0651	0.0651	0.6	0.45
Welding current *gas flow rate	IF	1	0.1038	0.1038	0.96	*0.343
Welding voltage *welding speed	VS	1	0.6211	0.6211	5.76	0.031
Welding voltage *gas flow rate	VF	1	0.0078	0.0078	0.07	0.791
Welding speed * gas flow rate	SF	1	0.2715	0.2715	2.52	*0.135
Error		10	1.5085	0.1077		
Pure error			0.1714	0.0343		
Lack of fit			1.3370	0.1485	4.33	0.061
Total			6.4740	-		

R-Sq = 86. 70 %

Table 4, shows that percentage dilution have more influence on porosity and gas flow rate interactions i.e: Current and gas flow rate(IF), voltage and gas flow rate(VF), Speed and gas flow rate (SF) and Current and gas flow rate(IF) displayed significant factor values for Adj SS of 0.1038, 0.0078, 0.2715 and 0.0756 respectively. The values of Adj SS were same with that of values of Adj MS. The F-values are larger than the P-values. The smallest P-value or the significant factor which is current gives a more significant effect on the response parameter, dilution. The P-value of 0.135 for interaction between gas flow rate and speed (SF), and the P-value of 0.343 for the interaction between current and gas flow rate (IF) are significant and they affect percentage dilution greatly.

This research claims that, percentage dilution strongly depends on the gas flow rate and can be controlled with a correct shielding gas flow rate that can provide on efficient gas coverage devoid of gas wastage at a Gas Tungsten Arc Welding (GTAW) process.

Determination of main and interaction for Percentage Dilution (%D) (%)

The plot of current versus percentage dilution as presented in fig 3, shows the effect of medium current on percentage dilution. Percentage dilution is minimized with medium current. It is minimized when current is at medium level with a value of 160amp and optimal parameter settings that will yield minimum percentage dilution is achieved at a medium current.

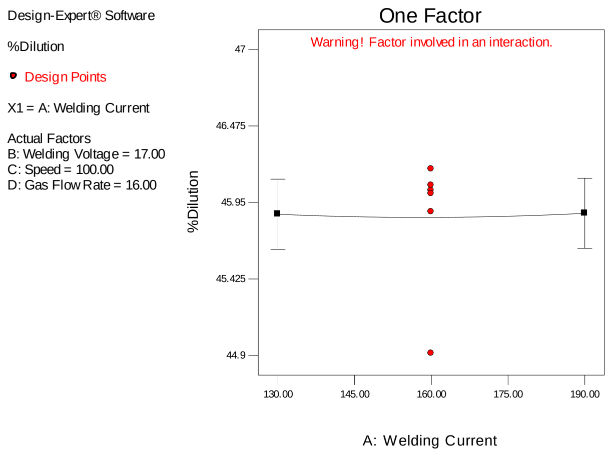

Fig. 3: Effects of Current Vs Percentage Dilution

The plot of gas flow rate versus percentage dilution as presented in fig 4, shows the effect of medium gas flow rate on percentage dilution. Percentage dilution is minimized with a high gas flow rate value of 16lit/min and optimal parameter settings that will yield minimum percentage dilution is achieved at a high gas flow rate.

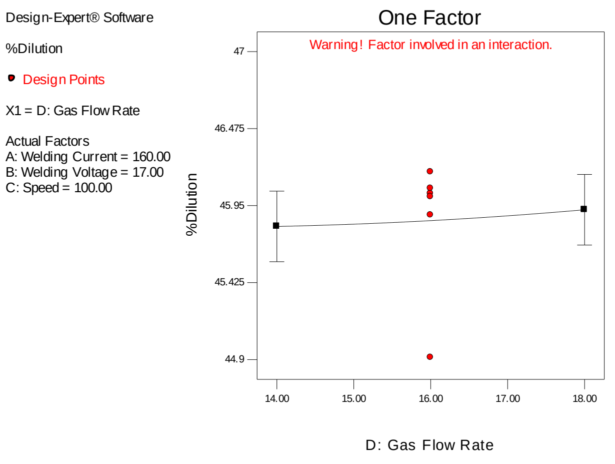

Fig. 4: Effects of gas flow rate Vs Percentage Dilution.

Effects of voltage and speed Vs percentage dilution yielded a minimized optimal value of percentage dilution of 45.67% with a high gas flow rate of 16lit/min and a current of 160amperes.

The effect of welding voltage on percentage dilution (%D) depends on the level of speed, represented by two lines on the graph. On the lower line, there is no overlap in the Interactive factor plot (IFP) bars at left versus right indicating a low speed. On the top line on the graph where speed is set at its highest level (+C), the IFP bars overlap indicating that the effect of voltage is significant. medium voltage and low speed results in a value of 45.9% for percentage dilution. Therefore, for a multi response optimization for the weld percentage dilution, the best settings are medium speed, medium voltage.

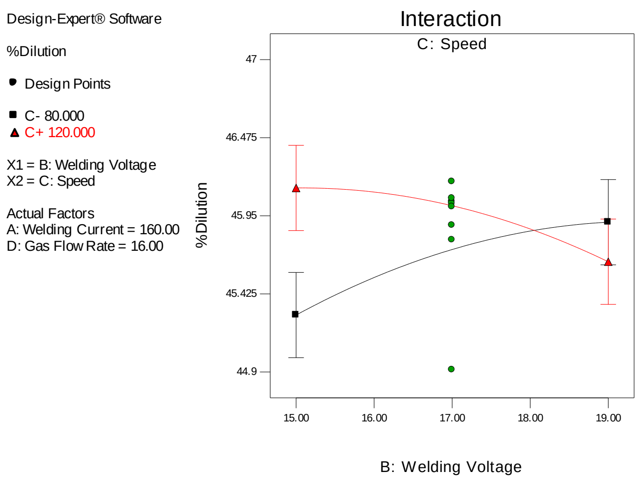

Fig 5: Effects of voltage and speed (VS) Vs Percentage Dilution

TABLE 5: ANALYSIS OF VARIANCE (ANOVA) FOR HEAT INPUT RATIO

S/N	Designation	Process parameter	Df	Adj SS	Adj MS	F-value	P-value
1	I	Welding current	1	18.7538	18.7535	30.26	0
2	V	Welding voltage	1	0.1258	0.1258	0.2	0.662
3	S	Welding speed	1	0.0452	0.0452	0.07	0.793
4	F	Gas flow rate	-	-	-	-	-
interaction							
5	IV	Current* voltage	1	0.0377	0.0377	0.06	0.81
6	IS	Current* speed√	1	0.7881	0.7881	1.27	0.286
7	IF	Current* gas flow rate	-	-	-	-	-
8	VS	Voltage* speed	1	0.0189	0.0189	0.03	0.865
9	VF	Voltage* gas flow rate	-	-	-	-	-
10	SF	Voltage* gas flow rate	-	-	-	-	-
		Error		6.1978	0.6198	-	-
		Lack of fit		2.3847	0.4769	0.63	0.69
		Pure error		0.8131	0.7626	-	-
		Total		28.018			

From Table 5, the smallest P-value of Zero (0) for current, indicates that current has the most significant effect on heat input with voltage, as both voltage and current are directly proportional to heat input ratio. As current and voltage increases, heat input ratio increases as well as, an increase in Heat Input decreases the welding speed.The other factor such as gas flow is insignificant.

Determination of main and interactive effect of H.IR

The Interactive Factor (IFP) plot of current versus heat input ratio as presented in fig 6 , shows the effect of high current on heat input ratio. Heat input ratio increase with increase in current. H.I.R. is maximum when current is at a high level and optimal parameter settings that will yield maximum heat input ratio (HIR) is achieved at a high current.

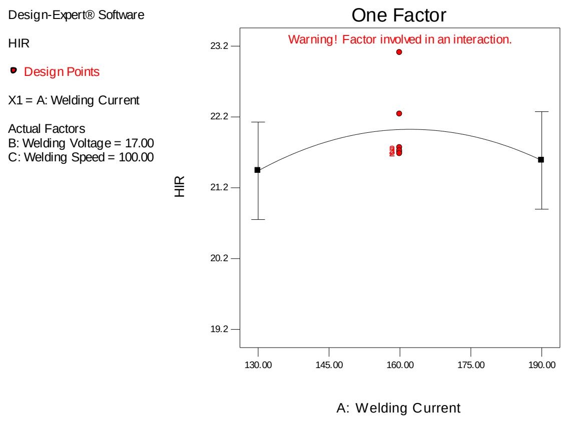

Fig. 6: Effects of current Vs Heat Input Ratio

Effects of current and speed on heat input ratio:

Heat input is significant when speed is low at a value of 80mm/min, current is high at a value of 189amperes with a voltage of 17volts. Hence, current is inversely proportional to speed.

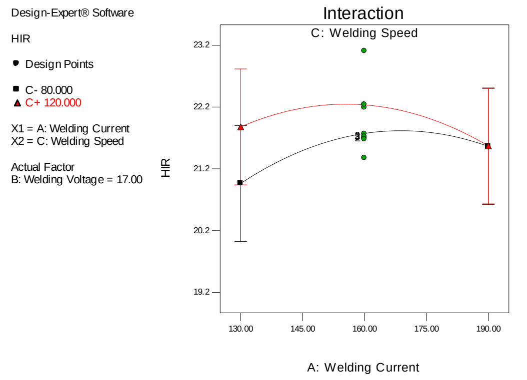

Fig 7: Effects of Current and Speed (IS) Vs Heat Input Ratio

TABLE 6: FACTORS WITH OPTIMUM LEVELS FOR PERCENTAGE (%D) DILUTION AND HEAT INPUT RATIO (H.I.R)

Process parameter	Optimum value for %D	Optimum value for H.I.R	Optimum level for % D	Optimum level for H.I.R
Welding current (Ampere)	45.94%	21.2kJ/min	High current	High current
Welding voltage (volts)	45.71%	21.9KJ/min	Medium voltage	Medium Voltage
Welding speed (mm/min)	45.95%	21.5KJ/min	Medium speed	Low speed
Gas flow rate (Lit/min)	45.95%	21.5KJ/min	High gas flow rate	High gas flow rate

Optimal value for %D 45.98%

Optimal value for HIR 21.53KJ/min

Optimal value for Gas flow rate 16lit/min .

8. CONCLUSIONS

1. The optimum condition for percentage dilution and gas flow rate is shown in table 6
2. The optimal condition for gas flow rate for a porosity – free weld is 16lit/min, current is 160 Amp, voltage is 17volts and speed is 100 mm/min
3. The main effect of importance is the gas flow rate and the interactive effect that affect the model the most ,is speed and gas flow rate(SF).
4. For percentage dilution, gas flow rate and speed are the most significant factors with a low P-value of 0.135.
5. Interactive Factor Plot (IFP) method of optimization is suitable to optimize the gas flow rate and the percentage dilution as adopted in the present study.
6. Gas Flow rate not too high, speed at a medium quantity, increased current and a medium quantity of voltage ,will reduce gas wastage at a GTAW process and eradicate porosity in the welds produced..
7. Porosity defect is eliminated in the weld produced with optimized parameter setting of
   Current I = 160Amperes
   Voltage V = 17volts
   Speed S = 100mm/min
   Gas flow rate F = 16 lit/min .
8. Percentage dilution optimal value is 45.9% and heat input ratio optimal value is 21.53kJ/min.

9. CONTRIBUTION TO KNOWLEDGE

1. A New Model has been developed.
2. A defined optimal value of 45.9 % of percentage dilution to be used at a GTAW process to prevent weld porosity. has been established.
3. A defined optimal value of 21.5 kJ/min for Heat Input ratio to be used at a gas tungsten arc welding process to prevent weld porosity , has been established.
4. A data bank for the welding industry has been created for the optimal values to be used at a GTAW process for :gas flow rate 16 lit /min , welding current 160 amperes ,welding speed 100 mm/min and welding voltage value of 17 volts.
5. Weld porosity is eliminated visiting the Data bank of this research.

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