

Research Article

The Influence of Process Parameters on Weld Droplet Diameter in MIG Welding: An Experimental Study

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Abstract

Metal Inert Gas (MIG) welding is a widely utilized welding process due to its efficiency and versatility. The weld droplet diameter is a critical parameter that significantly influences weld quality, including bead geometry, penetration, and mechanical properties. This study investigates the effects of welding current, voltage, and wire feed rate on the weld droplet diameter using locally sourced materials. A design of experiments (DOE) approach was employed, with parent samples measuring 40mm × 40mm × 10mm. Twenty experimental runs were conducted, and the results were analyzed using ANOVA. The findings reveal that voltage and current have a significant impact on the droplet diameter, while the wire feed rate exhibits negligible influence. A mathematical model was developed to predict the droplet diameter, and optimization was performed to identify the optimal process parameters. The model demonstrated a high R^2 value of 0.9008, indicating a strong correlation between the predicted and experimental results. The optimal parameters for achieving a droplet diameter of 1.024mm were identified as a current of 240A, a voltage of 24.168V, and a wire feed rate of 3.0mm/s. This study provides valuable insights into the relationship between process parameters and droplet diameter, offering a framework for optimizing MIG welding to enhance weld quality.

Keywords

MIG, Shielding Gas, Wire Feed Rate, Droplet Diameter

1. Introduction

Gas Metal Arc Welding (GMAW) or Metal Inert Gas (MIG) welding is one of the most widely used welding processes in various industries due to its versatility, efficiency, and ability to produce high-quality welds [1, 2]. The process involves the formation of an electric arc between a consumable wire electrode and the workpiece, which melts the electrode and forms a weld pool. The molten metal is transferred across the arc in the form of droplets, which significantly influence the weld bead geometry, penetration depth, and overall weld quality [3, 4]. Among the critical parameters in MIG welding, the weld droplet diameter plays a pivotal role in determining the sta-

bility of the welding process and the mechanical properties of the final weld [5, 6].

The droplet diameter is influenced by several process parameters, including welding current, voltage, and wire feed rate [7, 8]. Understanding the relationship between these parameters and the droplet diameter is essential for optimizing the welding process to achieve desired weld characteristics [9, 10]. Previous studies have highlighted the importance of controlling droplet transfer behavior to minimize defects such as spatter, porosity, and incomplete fusion [11, 12]. However, there is a need for further research to quantify the effects of

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specific process parameters on droplet diameter, particularly for locally sourced materials and specific workpiece dimensions [13-15].

This study focuses on investigating the effects of welding current, voltage, and wire feed rate on the weld droplet diameter using parent samples with dimensions of 40mm × 40mm × 10mm [16, 17]. All materials used in this research were locally purchased, ensuring the relevance of the findings to regional manufacturing practices [18, 19]. A design of experiments (DOE) approach was employed to systematically vary the process parameters and analyze their impact on the droplet diameter [20, 21]. The results were statistically analyzed using ANOVA, and a mathematical model was developed to predict the droplet diameter based on the input parameters [22, 23].

The primary objective of this research is to provide a comprehensive understanding of the relationship between process parameters and droplet diameter in MIG welding [24, 25]. By identifying the optimal combination of current, voltage, and wire feed rate, this study aims to enhance the quality and efficiency of the welding process, particularly for applications involving similar materials and workpiece dimensions. The findings of this research are expected to contribute to the broader body of knowledge on MIG welding and provide practical insights for welders and engineers seeking to optimize their welding processes.

2. Materials and Methods

2.1. Materials

All materials used in this study were locally sourced to ensure relevance to regional manufacturing practices. The parent samples were prepared from mild steel plates with dimensions of 40mm × 40mm × 10mm. The welding wire used was a mild steel electrode with a diameter of 1.2mm, compatible with the base material. Shielding gas, a mixture of 75% argon and 25% carbon dioxide (Ar-CO₂), was employed to protect the weld pool from atmospheric contamination and ensure stable arc characteristics. The chemical composition and mechanical properties of the base material and welding wire were verified to meet standard specifications.

2.2. Experimental Design

A full factorial design of experiments (DOE) was employed to systematically investigate the effects of welding current, voltage, and wire feed rate on the weld droplet diameter. The three factors and their respective ranges are presented in Table 1.

Table 1. Factors and Their Ranges.

Range	Factor 1: Current (A)	Factor 2: Voltage (V)	Factor 3: Wire Feed Rate (mm/s)
Min	240	23	2.4
Max	270	26	3.0

The experimental design consisted of 20 runs, with combinations of the factors varied within the specified ranges. The response variable measured was the weld droplet diameter (mm), which was recorded for each experimental run.

2.3. Experimental Setup and Procedure

The MIG welding experiments were conducted using a semi-automatic welding machine equipped with a wire feeder and a shielding gas supply. The welding torch was positioned at a 75° angle to the workpiece, and the arc length was maintained consistently throughout the experiments. The welding parameters for each run were set according to the DOE matrix, and the welding process was carried out under controlled conditions to ensure reproducibility.

After each weld, the droplet diameter was measured using a high-resolution optical microscope. The measurements were taken at multiple locations along the weld bead to ensure accuracy and consistency. The average droplet diameter for each run was recorded as the response variable.

2.4. Data Collection and Analysis

The experimental results are presented in Table 2. The data were analyzed using Analysis of Variance (ANOVA) to determine the significance of each factor and their interactions on the droplet diameter. A mathematical model was developed to predict the droplet diameter based on the input parameters, and the model's accuracy was validated using statistical metrics such as R², adjusted R², and predicted R².

Table 2. Experimental Results.

Std	Run	Factor 1	Factor 2	Factor 3	Response 1
		A: Current	B: Voltage	C: Wire feed rate	Droplet diameter
		A	V	mm/s	mm
17	1	250	24	2.6	1.16
9	2	260	23	2.8	0.96
10	3	240	25	2.8	1.13
12	4	250	24	2.6	1
20	5	250	24	2.6	1.16
18	6	250	26	2.6	0.71
16	7	260	25	2.8	0.92
3	8	250	24	2.6	1.17
14	9	240	25	2.4	1.01
8	10	250	24	2.6	1.23
4	11	260	23	2.4	1.26
5	12	240	24	2.6	1.3
2	13	260	25	2.4	0.72
7	14	250	23	2.6	1.07
19	15	270	24	2.6	1.1
11	16	250	24	2.4	1.13
6	17	250	24	3	0.95
15	18	240	23	2.4	1.33
1	19	240	23	2.8	0.98
13	20	250	24	2.6	1.26

3. Results and Discussion

3.1. Analysis of Variance (ANOVA)

The ANOVA results for the droplet diameter are presented in Table 3. The model was found to be statistically significant, with a p-value of 0.0006, indicating that the factors and their

interactions have a significant effect on the droplet diameter. Among the factors, voltage (Factor B) had the most significant impact, with an F-value of 16.94 and a p-value of 0.0021. Current (Factor A) also showed a significant effect, with an F-value of 5.80 and a p-value of 0.0367. In contrast, the wire feed rate (Factor C) had a negligible effect, with a p-value of 0.8624.

Table 3. ANOVA for Droplet Diameter.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.5127	9	0.0570	10.09	0.0006	Significant
A-Current	0.0328	1	0.0328	5.80	0.0367	

Source	Sum of Squares	df	Mean Square	F-value	p-value	
B-Voltage	0.0957	1	0.0957	16.94	0.0021	
C-Wire feed rate	0.0002	1	0.0002	0.0316	0.8624	
AB	0.0210	1	0.0210	3.72	0.0826	
AC	0.0021	1	0.0021	0.3741	0.5544	
BC	0.1176	1	0.1176	20.83	0.0010	
A ²	0.0065	1	0.0065	1.15	0.3096	
B ²	0.0953	1	0.0953	16.87	0.0021	
C ²	0.0230	1	0.0230	4.08	0.0711	
Residual	0.0565	10	0.0056			
Lack of Fit	0.0159	5	0.0032	0.3932	0.8357	not significant
Pure Error	0.0405	5	0.0081			
Cor Total	0.5692	19				

The interaction between voltage and wire feed rate (BC) was also significant, with an F-value of 20.83 and a p-value of 0.0010. This suggests that the combined effect of voltage and wire feed rate plays a critical role in determining the droplet diameter. The lack of fit test was not significant (p-value = 0.8357), indicating that the model adequately fits the experimental data.

3.2. Mathematical Model and Fit Statistics

A second-order polynomial equation was derived to model the relationship between the process parameters and the droplet diameter (DD) given in Equation 1. The equation is as follows:

$$DD = -24.23846 - 0.015794A + 3.68196B - 11.35050C - 0.005125AB + 0.008125AC + 0.606250BC + 0.000220A^2 - 0.084397B^2 - 1.03726C^2 \quad (1)$$

Where:

A = Current,

B = Voltage,

C = Wire feed rate.

The model was used to perform optimization and identify the optimal combination of parameters for achieving the desired droplet diameter. Contour plots and 3D surface plots were generated to visualize the effects of the factors on the response variable.

The fit statistics for the model are presented in Table 4. The model exhibited a high R² value of 0.9008, indicating that 90.08% of the variability in the droplet diameter can be explained by the model. The adjusted R² value of 0.8115 and the predicted R² value of 0.6249 further confirm the model's accuracy and predictive capability.

Table 4. Fit Statistics.

Std. Dev.	Mean	C.V.%	R ²	Adjusted R ²	Predicted R ²
0.0751	1.08	6.97	0.9008	0.8115	0.6249

3.3. Diagnostic Report

Table 5 presents a diagnostic report evaluating the performance of the predictive model by comparing actual and predicted values, along with various statistical metrics. The table includes 20 runs, each showing the actual value, predicted value, residual (difference between actual and predicted), leverage, internally and externally studentized residuals, Cook's distance, influence on fitted value (DFFITS), and standard order. Key observations include Run 6, which shows a high externally studentized residual (1.346) and significant influence on the fitted value (DFFITS = 2.846^(*)), indicating a potential outlier. Similarly, Run 3 exhibits a high Cook's distance (0.353) and a large externally studentized residual (-1.198), suggesting it has a notable impact on the model. Runs 10 and 12 also show relatively high residuals (1.097 and 0.709, respectively), but their influence on the model is moderate, as indicated by their Cook's distance and DFFITS values. Overall, the diagnostic report highlights the model's accuracy, with most runs showing low residuals and minimal influence on the fitted values, except for a few outliers that may require further investigation. This analysis

ensures the robustness and reliability of the predictive model.

Table 5. Diagnostic Report.

Run Order	Actual Value	Predicted Value	Residual	Leverage	Internally Studentized Residuals	Externally Studentized Residuals	Cook's Distance	Influence on Fitted Value DFFITS	Standard Order
1	1.16	1.15	0.0058	0.138	0.083	0.079	0.000	0.032	17
2	0.9600	0.9613	-0.0013	0.720	-0.032	-0.031	0.000	-0.049	9
3	1.13	1.18	-0.0466	0.720	-1.173	-1.198	0.353	-1.920	10
4	1.0000	1.15	-0.1542	0.138	-2.210	-2.931	0.078	-1.172	12
5	1.16	1.15	0.0058	0.138	0.083	0.079	0.000	0.032	20
6	0.7100	0.6684	0.0416	0.817	1.295	1.346	0.749	2.846	18
7	0.9200	0.9531	-0.0331	0.636	-0.729	-0.711	0.093	-0.940	16
8	1.17	1.15	0.0158	0.138	0.226	0.215	0.001	0.086	3
9	1.01	1.03	-0.0218	0.778	-0.617	-0.596	0.133	-1.116	14
10	1.23	1.15	0.0758	0.138	1.086	1.097	0.019	0.439	8
11	1.26	1.24	0.0235	0.778	0.664	0.644	0.154	1.206	4
12	1.30	1.25	0.0470	0.261	0.728	0.709	0.019	0.422	5
13	0.7200	0.7433	-0.0233	0.720	-0.585	-0.565	0.088	-0.905	2
14	1.07	1.14	-0.0739	0.261	-1.144	-1.164	0.046	-0.692	7
15	1.10	1.09	0.0114	0.817	0.354	0.338	0.056	0.714	19
16	1.13	1.15	-0.0153	0.261	-0.237	-0.225	0.002	-0.134	11
17	0.9500	0.9230	0.0270	0.817	0.839	0.825	0.314	1.745	6
18	1.33	1.32	0.0099	0.810	0.304	0.289	0.039	0.598	15
19	0.9800	0.9799	0.0001	0.778	0.004	0.004	0.000	0.007	1
20	1.26	1.15	0.1058	0.138	1.516	1.639	0.037	0.655	13

3.4. Optimization of Process Parameters

The optimization results are presented in Table 6. The optimal parameters for achieving a droplet diameter of 1.024mm

were identified as:

- 1) Current: 240 A,
- 2) Voltage: 24.168 V,
- 3) Wire feed rate: 3.0mm/s.

Table 6. Optimization Prediction Results.

Number	Current (A)	Voltage (V)	Wire Feed Rate (mm/s)	Droplet Diameter (mm)	Desirability
1	240.000	24.168	3.000	1.024	0.801

The desirability value of 0.801 indicates a high level of confidence in the optimized parameters. These results provide prac-

tical guidance for welders and engineers seeking to achieve consistent droplet diameters and improve weld quality.

3.5. Graphical Analysis

The relationship between the process parameters and the droplet diameter was further analyzed using contour plots and 3D surface plots (Figures 1-3). These plots provide a visual

representation of the effects of current, voltage, and wire feed rate on the droplet diameter. Figure 2 shows that the droplet diameter decreases with increasing voltage and wire feed rate, while Figure 3 illustrates the combined effect of current and voltage on the droplet diameter.

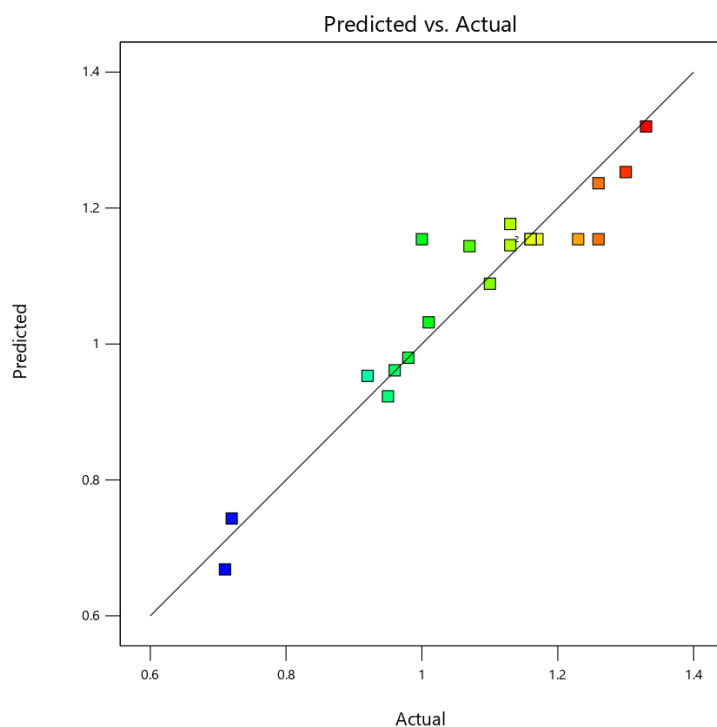


Figure 1. Predicted Vs Actual for Droplet Diameter.

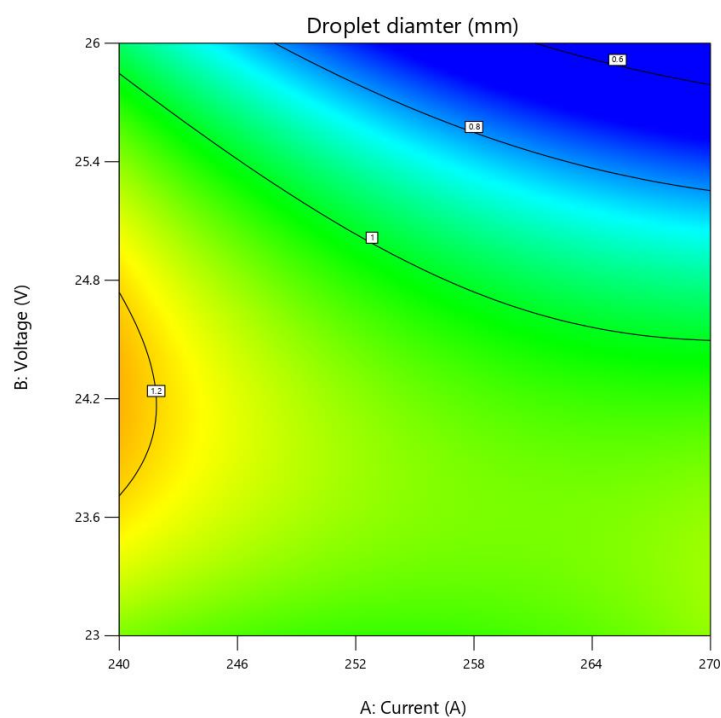


Figure 2. Contour for Droplet Diameter.

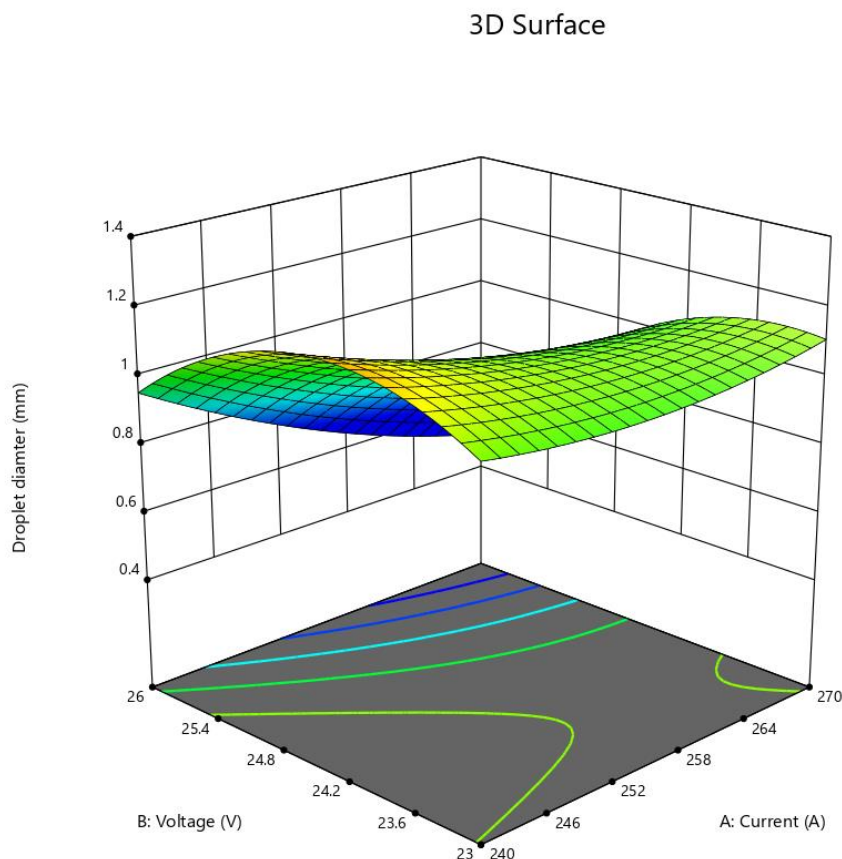


Figure 3. 3D Surface Plot for Droplet Diameter.

3.6. Practical Implications

The findings of this study have significant practical implications for the welding industry. By understanding the effects of process parameters on droplet diameter, welders can optimize their welding procedures to minimize defects such as spatter, porosity, and incomplete fusion. The mathematical model developed in this study can be used as a predictive tool to estimate the droplet diameter for a given set of parameters, reducing the need for trial-and-error experimentation.

3.7. Limitations and Future Work

While this study provides valuable insights into the relationship between process parameters and droplet diameter, there are some limitations. The experiments were conducted using a specific material and workpiece geometry, and the results may not be directly applicable to other materials or configurations. Future work could explore the effects of additional factors, such as shielding gas composition and torch angle, on droplet diameter. Additionally, the model could be validated using real-world welding applications to further enhance its accuracy and reliability.

4. Conclusion

This study investigated the effects of welding current, voltage, and wire feed rate on the weld droplet diameter in the Metal Inert Gas (MIG) welding process using locally sourced materials. A design of experiments (DOE) approach was employed to systematically vary the process parameters, and the results were analyzed using ANOVA to determine the significance of each factor and their interactions. The findings reveal that voltage and current significantly influence the droplet diameter, while the wire feed rate has a negligible effect. Specifically, higher voltages led to smaller droplets due to a more stable arc and finer droplet transfer, whereas higher currents resulted in larger droplets due to increased electrode melting. The interaction between voltage and wire feed rate was also found to be significant, highlighting the importance of optimizing these parameters together.

A second-order polynomial equation was developed to predict the droplet diameter based on the input parameters. The model exhibited a high R^2 value of 0.9008, indicating a strong correlation between the predicted and experimental results. This mathematical model serves as a valuable tool for welders and engineers to estimate the droplet diameter for a given set of parameters, reducing the need for trial-and-error

experimentation. Furthermore, optimization was performed to identify the optimal combination of parameters for achieving a droplet diameter of 1.024mm. The optimal parameters were determined to be a current of 240A, a voltage of 24.168V, and a wire feed rate of 3.0mm/s. These results provide practical guidance for improving weld quality and consistency in real-world applications.

The findings of this study have significant practical implications for the welding industry. By understanding the effects of process parameters on droplet diameter, welders can optimize their welding procedures to minimize defects such as spatter, porosity, and incomplete fusion. This not only enhances the mechanical properties of the weld but also improves productivity and reduces material waste. However, it is important to note that the study was conducted using a specific material and workpiece geometry, and the results may not be directly applicable to other configurations. Future work could explore the effects of additional factors, such as shielding gas composition and torch angle, on droplet diameter. Additionally, the model could be validated using real-world welding applications to further enhance its accuracy and reliability.

Abbreviations

MIG	Metal Inert Gas
GMAW	Gas Metal Arc Welding
DOE	Design of Experiments
ANOVA	Analysis of Variance
R ²	Coefficient of Determination (R-squared)
A	Current (in the Mathematical Model)
V	Voltage (in the Mathematical Model)
mm/s	Millimeters per Second (Wire Feed Rate Unit)
DD	Droplet Diameter
df	Degrees of Freedom (in ANOVA Table)
Std	Standard (in Experimental Results Table)
Run	Experimental Run (in Tables)
Min	Minimum
Max	Maximum
C.V.	Coefficient of Variation
Std. Dev.	Standard Deviation
DFFITS	Influence on Fitted Value (Diagnostic Metric)

Conflicts of Interest

The authors declare no conflicts of interest.

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