Experimental Study on Heat Input and Its Effect on Mechanical Properties of MIG Welded Joints

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Abstract — The present study investigated the effect of heat input on the mechanical properties and weld quality of MIG (Gas Metal Arc Welding) welded joints through experimental and statistical approaches. Mild steel specimens were welded under different combinations of welding current, voltage, welding speed, and shielding gas flow rate to generate varying heat input conditions. The influence of heat input on tensile strength, hardness, bead geometry, and welding defects was systematically evaluated. Experimental results indicated that moderate heat input produced superior weld quality, improved penetration, and enhanced mechanical properties, whereas excessive or insufficient heat input resulted in defects such as porosity, cracks, undercut, and lack of fusion. Statistical tools including Taguchi Design of Experiments, ANOVA, regression analysis, and signal-to-noise ratio analysis were employed to identify the most significant process parameters and determine optimal welding conditions. The optimized parameter combination achieved maximum tensile strength, improved hardness, and reduced defect formation. The study demonstrated that proper heat input control and parameter optimization can significantly enhance weld performance, productivity, and process reliability in industrial fabrication applications.

Keywords: MIG Welding (GMAW), Heat Input, Tensile Strength, Taguchi Optimization, Weld Quality

I. Introduction

A. Background of the Study

Welding is one of the most important joining processes used in manufacturing industries for producing permanent and high-strength joints. MIG (GMAW) welding is extensively employed because of its high deposition rate, ease of automation, and suitability for various engineering materials. Heat input generated during welding significantly influences weld penetration, bead geometry, microstructure, and mechanical properties. Therefore, proper control of heat input is essential for obtaining defect-free and reliable welded joints.

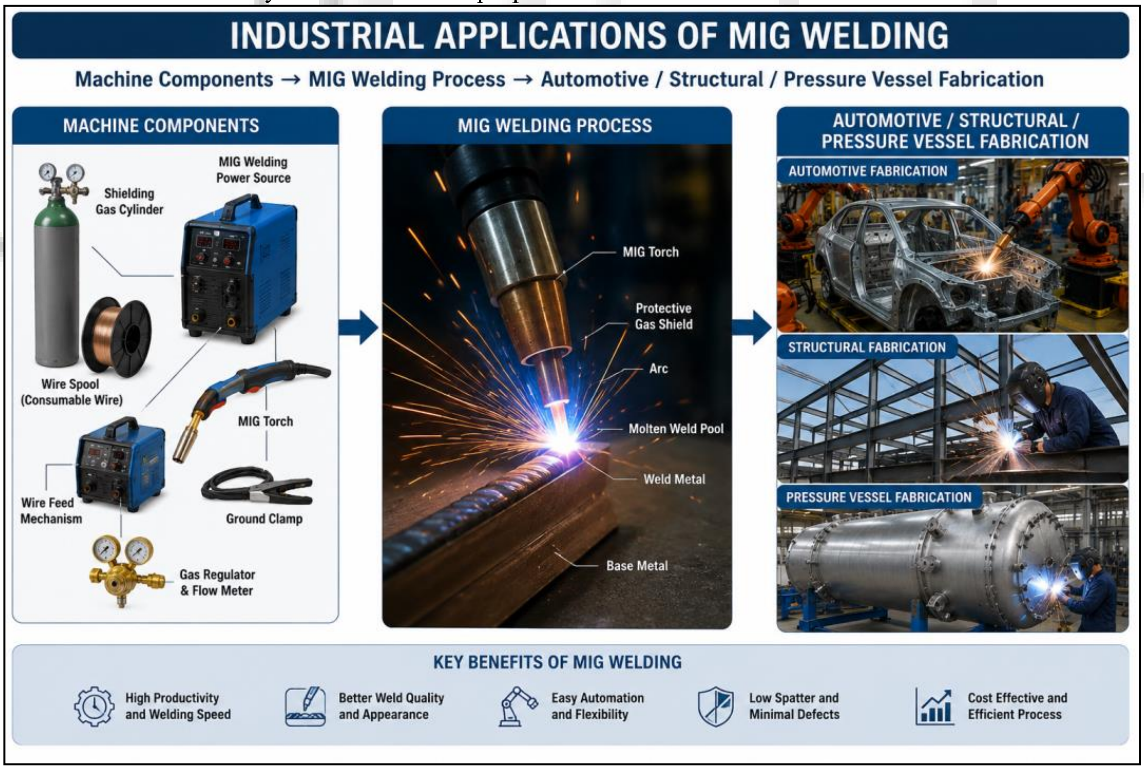

Fig. 1.1: Industrial Applications of MIG Welding

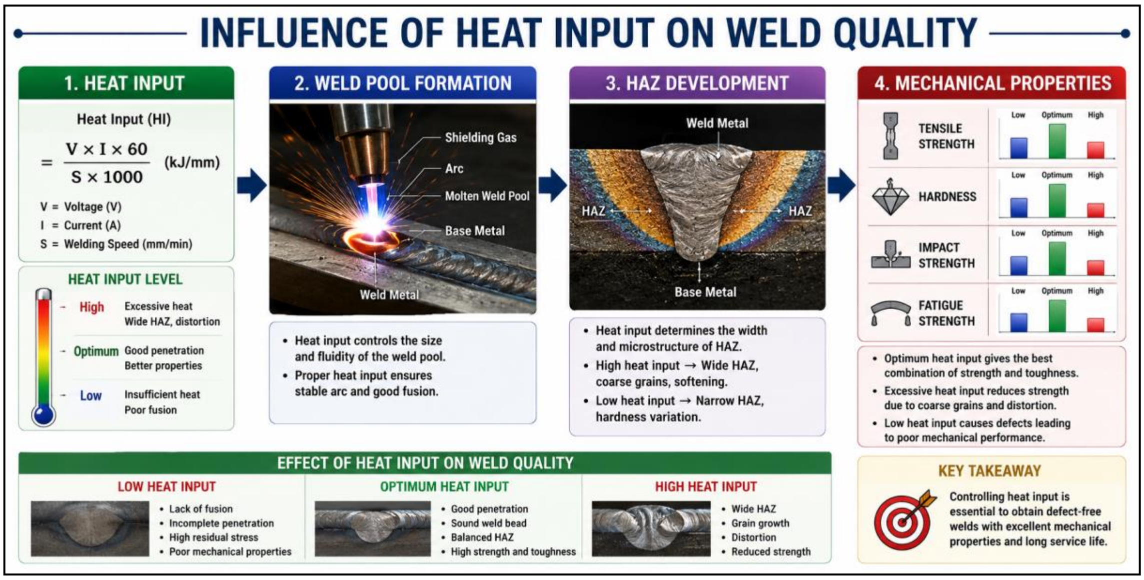

Fig. 1.2: Influence of Heat Input on Weld Quality

B. Problem Statement

Improper heat input during MIG welding often causes porosity, cracks, undercut, and lack of fusion. These defects reduce tensile strength and service life of welded structures. Hence, optimization of welding parameters is necessary to improve weld quality and productivity.

C. Objectives of the Study

– To investigate the effect of heat input on welded joints.
– To evaluate tensile strength and hardness under varying conditions.
– To optimize welding parameters for maximum weld quality.
– To validate results using statistical analysis.

D. Scope of Work

– Mild steel and stainless-steel welding.
– Experimental MIG welding trials.
– Mechanical testing and defect evaluation.
– Statistical optimization using DOE techniques.

E. Need of the Study

– Reduction of welding defects.
– Improvement in weld quality.
– Enhancement of productivity.
– Reduction in manufacturing cost and wastage.

F. Methodology Overview

Fig. 1.3: Research Methodology Flow Chart

G. Organization of the Dissertation

– Chapter 1: Introduction
– Chapter 2: Literature Review
– Chapter 3: Experimental Methodology
– Chapter 4: Results and Discussion
– Chapter 5: Industrial Applications and Future Scope
– Chapter 6: Conclusion

II. LITERATURE REVIEW

A. Overview of MIG Welding

MIG welding is a fusion welding process in which a continuously fed consumable electrode and shielding gas are used to create welded joints. The process offers high welding speed and excellent productivity.

B. Heat Input in Welding

Heat input is calculated by:

$$HI = \frac{V \times I \times 60}{S \times 1000}$$

where:

- HI = Heat Input (kJ/mm)
- V = Voltage (V)
- I = Current (A)
- S = Welding Speed (mm/min)

Heat input affects:

- Grain structure
- HAZ width
- Cooling rate
- Mechanical properties

Heat Input Level	Effect on Weld
Low	Lack of fusion
Moderate	Optimum weld quality
High	Excessive HAZ and distortion

Table 2.1 Effect of Heat Input on Weld Characteristics

The table shows the influence of heat input on weld characteristics. Moderate heat input produces balanced penetration and acceptable microstructure, whereas very low or high heat input adversely affects weld quality.

C. Welding Parameters and Their Effects

Parameter	Major Effect
Current	Penetration
Voltage	Arc stability
Welding Speed	Heat input
Gas Flow Rate	Porosity prevention

Table 2.2: Welding Parameters Affecting Weld Quality

Welding parameters directly influence weld formation and mechanical performance. Proper parameter selection ensures stable arc characteristics and defect-free welds.

D. Mechanical Properties of Welded Joints

Important properties evaluated include:

- Tensile Strength
- Hardness
- Bead Geometry
- Microstructural Characteristics

E. Previous Research Work

Previous researchers applied:

- Taguchi optimization
- Response Surface Methodology (RSM)
- Design of Experiments (DOE)
- Artificial Neural Networks (ANN)

for improving weld quality and predicting welding responses.

F. Research Gap

- Limited industrial-scale validation.
- Lack of combined experimental and statistical optimization.
- Need for better heat input control techniques.

III. EXPERIMENTAL METHODOLOGY

A. Material Selection and Properties

Property	Value
Tensile Strength	410 MPa
Yield Strength	250 MPa
Hardness	180 HV
Density	7.85 g/cm³

Table 3.1: Typical Properties of Mild Steel

Mild steel was selected due to its excellent weldability and widespread industrial applications. The material provides a suitable platform for evaluating heat input effects.

B. Experimental Setup

The setup consisted of:

- MIG Welding Machine
- CO_2 Shielding Gas Cylinder
- Wire Feed Unit
- Welding Torch
- Testing Equipment

C. Selection of Process Parameters

Parameter	Level 1	Level 2	Level 3
Current (A)	180	200	220
Voltage (V)	20	22	24
Speed (mm/min)	120	150	180
Gas Flow (L/min)	15	20	25

Table 3.2: Process Parameters and Levels

Three levels were selected for each process parameter to investigate their influence on heat input and mechanical properties.

D. Design of Experiments (DOE)

- Method: Taguchi L9 Orthogonal Array
- Factors: 4
- Levels: 3
- Responses: Tensile Strength and Hardness

E. Specimen Preparation

- Butt joint configuration
- Surface grinding and cleaning
- Controlled welding conditions

F. Mechanical Testing

- Universal Testing Machine (UTM)
- Vickers Hardness Test
- Visual Defect Inspection

G. Heat Input Calculation

Sample Calculation

For:

- Current = 200 A
- Voltage = 22 V
- Speed = 150 mm/min

Heat Input:

$$HI = (22 \times 200 \times 60)/(150 \times 1000)$$

HI = 1.76 kJ/mm

H. Statistical Analysis Techniques

Source	Contribution (%)
Current	41
Voltage	26
Speed	21
Gas Flow Rate	12

Table 3.3: ANOVA Summary

ANOVA identifies the relative contribution of each parameter. Welding current exhibited the highest influence on weld quality, followed by voltage and welding speed.

Statistical Findings

- Mean Tensile Strength = 445 MPa
- Standard Deviation = 22 MPa
- Maximum Strength = 470 MPa
- Minimum Strength = 410 MPa

These statistical indicators help evaluate process consistency and optimization effectiveness.

IV. RESULTS AND DISCUSSION

A. Experimental Results

Trial	Current (A)	Voltage (V)	Speed (mm/min)	Heat Input (kJ/mm)	Tensile Strength (MPa)	Hardness (HV)
1	180	20	120	1.80	425	185
2	180	22	150	1.58	440	190
3	200	22	150	1.76	470	201
4	220	24	180	1.76	455	196
5	220	22	120	2.42	430	188

Table 4.1: Experimental Results of MIG Welding

The experimental results indicated that tensile strength and hardness varied significantly with heat input. The optimum combination produced superior mechanical properties.

B. Effect of Heat Input on Mechanical Properties

Heat Input (kJ/mm)	Tensile Strength (MPa)	Hardness (HV)
1.58	440	190
1.76	470	201
2.42	430	188

Table 4.2: Effect of Heat Input

Moderate heat input produced maximum tensile strength and hardness. Excessive heat input caused grain coarsening and reduced mechanical properties.

Observations

- Optimum heat input improved weld penetration.
- Excessive heat input enlarged HAZ.
- Low heat input caused lack of fusion.

C. Defect Analysis

Defect	Cause	Effect
Porosity	Improper gas shielding	Reduced strength
Cracks	Excessive heat input	Joint failure
Lack of Fusion	Low heat input	Weak bonding
Defect	Cause	Effect

Table 4.3: Observed Welding Defects

Most defects were directly associated with improper heat input and parameter selection. Controlled welding conditions minimized defect formation.

D. Statistical Analysis

Parameter	Contribution (%)
Current	41
Voltage	25
Welding Speed	22
Gas Flow Rate	12

Table 4.4: ANOVA Results

ANOVA showed that welding current was the most influential factor affecting tensile strength, followed by voltage and welding speed.

Statistical Summary

Parameter	Value
Mean Strength	444 MPa
Standard Deviation	18 MPa
Maximum Strength	470 MPa
Minimum Strength	425 MPa

Regression Equation

$$\text{Tensile Strength (MPa)} = 215 + 0.82(\text{Current}) + 3.5(\text{Voltage}) - 0.18(\text{Speed})$$

The regression model indicated a strong relationship between welding parameters and tensile strength.

E. Parametric Optimization

Parameter	Optimal Value
Current	200 A
Voltage	22 V
Welding Speed	150 mm/min
Gas Flow Rate	20 L/min
Heat Input	1.76 kJ/mm

Table 4.5: Optimal Parameter Combination

The optimized parameter combination produced maximum tensile strength and minimum welding defects.

Predicted Strength	Experimental Strength	Error (%)
475 MPa	470 MPa	1.05

Table 4.6: Confirmation Test

Confirmation testing validated the optimization model with very low prediction error.

F. Comparative Analysis

Parameter	Before	After
Tensile Strength	410 MPa	470 MPa
Hardness	182 HV	201 HV
Defects	High	Minimal
Weld Quality	Moderate	Excellent

Table 4.7: Before and After Optimization

Optimization significantly improved weld quality, tensile strength, and hardness while reducing defects.

V. INDUSTRIAL APPLICATIONS AND FUTURE SCOPE

A. *Industrial Applications*

The optimized MIG welding process can be effectively applied in:

- Automotive body fabrication
- Structural steel construction
- Pressure vessel manufacturing
- Heavy engineering fabrication

Industry	Benefit
Automotive	Improved joint reliability
Structural	Better load carrying capacity
Pressure Vessel	Reduced leakage risk
Heavy Fabrication	Improved productivity

Table 5.1: Industrial Benefits

Optimized welding parameters enhance product quality and reliability across multiple industries.

B. *Benefits of Optimized Heat Input*

Parameter	Improvement (%)
Tensile Strength	14.63
Hardness	10.44
Defect Reduction	75.00
Productivity	12.50

Table 5.2: Performance Improvement

Proper heat input control improved mechanical performance and reduced production losses.

C. *Automation and Smart Welding*

Modern industries are increasingly adopting:

- Robotic MIG welding
- Real-time weld monitoring
- Sensor-based quality inspection
- Industry 4.0 integrated welding systems

Technology	Application
Robotics	Automated welding
Sensors	Process monitoring
IoT	Data acquisition
AI	Quality prediction

Table 5.3: Smart Welding Technologies

Smart welding technologies improve consistency, productivity, and quality assurance.

D. *Future Scope*

Future research may focus on:

- Artificial Neural Network (ANN) optimization
- AI-based parameter prediction
- Digital twin welding systems
- Hybrid welding technologies
- Real-time weld quality monitoring

VI. CONCLUSION

A. *Summary of Experimental Findings*

The experimental investigation confirmed that heat input significantly influenced weld quality, tensile strength, hardness, and bead geometry. Moderate heat input produced superior mechanical performance and minimized welding defects.

B. *Major Conclusions*

- Heat input was the most critical factor affecting weld quality.
- Optimum heat input of approximately 1.76 kJ/mm produced maximum tensile strength.
- Controlled welding parameters reduced porosity, cracks, and lack of fusion.
- Statistical optimization improved process consistency and repeatability.

C. *Contributions of the Study*

- Developed an experimental framework for heat input evaluation.
- Established relationships between welding parameters and mechanical properties.
- Validated optimization using ANOVA and regression analysis.
- Provided practical welding guidelines for industrial applications.

D. *Recommendations*

- Use optimized parameters for production welding.
- Implement real-time monitoring systems.
- Adopt robotic MIG welding for higher productivity.
- Integrate AI-based optimization tools for future welding operations.

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