Experimental Investigation of Effect of MAG Welding Process Parameters on Mechanical Properties of ST35 Carbon Steel Joint

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Abstract— Metal Active gas arc welding (MAG) is preferable more its inherent qualities like easy control of variables, high quality, deep penetration, smooth finish and good Hardness and UTS. The quality of weld depends on its Mechanical Properties, Which in turn depends on the process parameters. In this present work, the effect of Taguchi Methodology approach for experimental investigation of Metal Active gas welding parameters like Voltage, Wire feed rate and Gas flow rate on Hardness, UTS and % Elongation are studied. DOE is made by MINITAB 18 software. ANOVA is used for finding contribution of each parameter on Response. Reggration Analysis is used for finding Mathematical Equation and Validation Purpose. Also GRA is used for Optimization purpose.
Keywords: MAG, ANOVA, GMAW

I. GAS METAL ARC WELDING (GMAW)

The principles of GMAW began to be understood in the early 19th century, after Humphry, Davy discovered the short pulsed electric arcs in 1800. Vasily Petrov, who independently produced the continuous electric arc in 1802 (soon followed by Davy). It was not until the 1880s, that the technology became developed with the aim of industrial usage. At first, carbon electrodes used in carbon arc welding. By 1890, metal electrodes had been invented by Nikolay Slavyanovand C. L. Coffin. In 1920, an early predecessor of GMAW was invented by P. O. Nobel of General Electric. It used a bare electrode wire and direct current, also used arc voltage to regulate the feed rate. It has not use the shielding gas to protect the weld, as developments in welding atmospheres did not take place until later that decade. In 1926 another forerunner of GMAW was released, but it was not suitable for practical use.

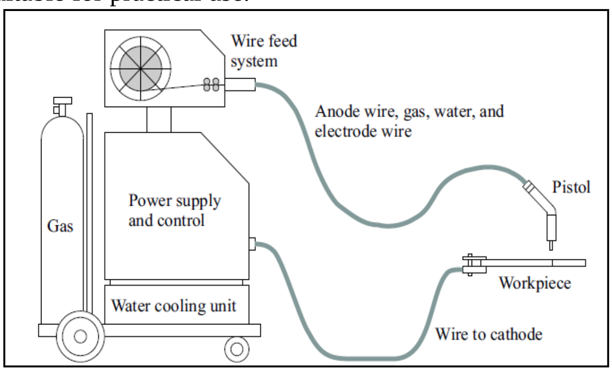


Fig. 1.1: MIG Machine Components [11]

GMAW is very famous in welding methods in industries. The problem can be alleviated to some extent by increasing the shielding gas output, but this can be expensive and may also affect the quality of the weld. In general, processes such as shielded metal arc welding and flux cored arc welding are preferred for welding outdoors, making the use of GMAW in the construction industry limited. Furthermore, the use of a shielding gas causes GMAW to be unpopular for the underwater welding also.[21]

A. Equipment

To perform gas metal arc welding, the basic necessary equipment is a welding gun, a wire feed unit, a welding power supply, an electrode wire, and a shielding gas supply.

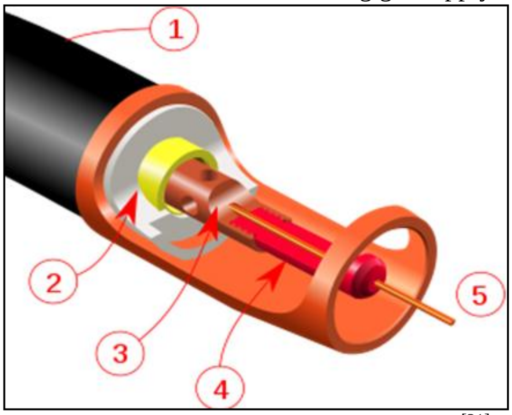


Fig. 1.2: Welding gun and wire feed unit [21]

B. Metal Transfer Modes

The three transfer modes in GMAW are globular, short-circuiting and spray.

C. Globular

At current lower than needed for spray transfer and with voltage above the pure short arc welding there is a mixed region characterized with droplets larger than the electrode diameter and often with irregular shape. The molten drop grows until it detaches by short-circuiting or by gravity. The Globular transfer mode is most often avoided.

D. Short Circuiting

With lower arc volts and currents transfer takes place in globular from but with intermittent short circuiting of the arc. The wire feed rate must just exceed the burn of rate so that the intermittent short circuiting will occur. When the wire touches the pool and short circuits the arc there is momentary rise of current which must be sufficient to make the wire tip molten, a neck is then formed in it due to magnetic pinch effect and it melts of in the form of a droplet being sucked into the molten pool added by surface tension. The arc is then re-established gradually reducing in length as the wire feed rate gains on the burn off until short circuiting again occurs. The power source must supply sufficient current on short circuit to ensure melt of or otherwise the wire will stick in to the pool, and it must also be able to provide sufficient voltage immediately after short circuit to establish the arc.

E. Spray

In manual metal arc welding, metal is transferred in globules or droplets from electrode to work. If the current is increase to the continuously fed gas shielded wire, the rate at which the droplets are projected across the arc increases and they become smaller in volume, the transfer occurring in the form of fine spray.

The type of gas being used as a shield greatly affects the value of current at which spray transfer occurs. Much greater current densities are required with CO_2 then with argon to obtain the same droplet rate. The arc is not extinguished during the operation period. So that arc energy output is high, the rate of deposition of metal is high, penetration is deep and there is considerable dilution. The high currents used to produce strong magnetic fields and very directional arc. Spray transfer is also termed free fight transfer. [21]

II. Literature Review

A. Parametric Optimization of Gas metal arc welding process by PCA based Taguchi method on Austenitic Stainless Steel AISI 316L

Nabendu Ghosh*a, Pradip Kumar Palb, Goutam Nandic and Ramesh Rudrapatid present paper on "Parametric Optimization of Gas metal arc welding process by PCA based Taguchi method on Austenitic Stainless Steel AISI 316L**"** This paper deals with the various welding parameters such as Current, Gas flow rate and Nozzle to plate distance were varied on AISI 316L and the effects of these parameters on Yield strength, UTS and % Elongation have been studied. They plot S/N ratio of multi-response performance index (MPI) and the result of various effects is discussed. [1]

B. Optimization of MIG welding process parameters for hardness and strength of welding joint using Grey relational analysis

D.Bahar1, Md. Nawaz Sharif2, K. Shravan Kumar3and D. Reddy4 present paper on "Optimization of MIG welding process parameters for hardness and strength of welding joint using Grey relational analysis." This paper deals with Gas Metal Arc Welding (GMAW) process is generally used in industry for high productivity and better quality. In this paper, the effects of various parameters on Voltage, Weld speed, Gas flow rate, Wire feed rate in SS 316 base metal. In this process,

For hardness, in optimization of UTS contribution of gas flow rate is higher. it is also observed that welding voltage and gas flow rate should be lower but wire feed rate and welding speed should be higher to optimize UTS. In multi response optimization i.e. optimization of hardness as well as UTS contribution of welding speed is higher and welding voltage should be high. [2]

C. Metal Inert Gas (MIG) Welding Process Optimization using Teaching-Learning Based Optimization (TLBO)

Bhagwan F. Jogia*, A. S. Awaleb, S. R. Nirantarc, H. S. Bhusared presents paper on "Metal Inert Gas (MIG) Welding Process Optimization using Teaching-Learning Based Optimization (TLBO)" This paper deals with Metal Inert Gas welding (MIG) process is an important process in many industrial operations. Gas metal arc welding parameters are the important factors affecting the productivity, quality and welding cost. This paper works with the parameters like Voltage, Gas flow rate, Wire feed rate, Orientation angle. Optimization of input parameters for MIG welding operation on AISI 1018 mild steel by using teaching-learning based optimization (TLBO) algorithm is performed. Various response variables like weld reinforcement, weld penetration and bead width are measured in each experiment. The results are analyzed to study the effect of each input parameter on the response variables by ANOVA. All response variables are significantly affected by welding current and welding voltage. It is evident from main effect plots that the increase in welding current considerably increases the weld penetration and the decrease in welding voltage considerably decrease the weld reinforcement and bead width. So that welding current and voltage shows statistical significance on overall MIG welding performance [3]

D. Evaluation of MIG welding process parameter using Activated Flux on SS316L by AHP-MOORA Method

Pavan G. Chaudhari a, Priyank B. Patelb, Jaksan D. Patel c presents paper on "Evaluation of MIG welding process parameter using Activated Flux on SS316L by AHP-MOORA Method" The present work concluded that in order to get effective selections of a MIG machine using SS316L material; it is necessary to consider possible alternatives and attributes. The MADM method, the AHP provides opportunity to select the best alternative of MIG machine considering with multi attributes having different measures. The priority or ranking of alternatives depends on attributes weight or relative importance assigned between attributes and on the values of the selected attributes. The AHP can handle tangible (objective) as well as non-tangible (subjective) attribute measures. It has been observed that MOORA method is very simple, stable and robust. It requires minimum Mathematical calculations and computational time [4]

E. Residual Stress Analysis in MIG Welding of Stainless Steel 409M

Pradeep Khanna*and Sachin Maheshwarib presents paper on "Residual Stress Analysis in MIG Welding of Stainless Steel 409M." This paper present, The maximum residual tensile stress recorded was 150.23N/mm2 at a distance of 18mm from the weld centerline in plate#5. The minimum residual tensile stress recorded was 120.28N/mm2 at a distance of 18mm from the weld centerline in plate#1.The maximum residual compressive stress was recorded -50.61N/mm2 at a distance of about 65mm from the weld centerline in plate#5. Increase in heat input increase the magnitude of the tensile residual stresses.[5]

F. Multi-Response Optimization of Process Parameters for MIG Welding of AA2219-T87 by Taguchi Grey Relational Analysis

Arunkumar Sivaramana, SathiyaPaulraja* presents paper on "Multi-Response Optimization of Process Parameters for MIG Welding of AA2219-T87 by Taguchi Grey Relational Analysis" This paper deals with Taguchi L9 array with grey relational analysis has been used to optimize the multiple performance characteristics such as tensile strength, transverse shrinkage and hardness. The optimized parameter found using GRA was current= 32 A, Voltage= 25 V, welding speed= 185 mm/sec. Based on the ANOVA results of GRA, it was observed that the welding current (82%) exerted a significant influence on multiple responses followed by welding speed (15%) and voltage (3%). The mechanical properties were correlated with the metallurgical characteristics. The microstructure of the weld region revealed finer cellular structure for experiment 4, whereas harder dendrites were formed for experiment 8 due to higher heat input. [6]

G. Parametric Optimization of Gas Metal Arc Welding Process by using Taguchi method on Ferritic Stainless Steel AISI409

Nabendu Ghosha, Ramesh Rudrapatib*, Pradip Kumar Palc, Gotam Nandic presents paper on ,” Parametric Optimization of Gas Metal Arc Welding Process by using Taguchi method on Ferritic Stainless Steel AISI409**”.** This paper deals with Results of visual inspection and X-ray radiographic tests. They are compared, some consistency are founds. ANOVA test results indicate that welding process parameters do not have significant influence on both the responses. Optimal parametric welding condition is (i.e. current (C) = 124 A, gas flow rate (G) = 10 l/min and nozzle to late distance (S) = 9 mm) obtained by Taguchi method for maximizing both the responses: UTS and PE. Confirmatory experiment results confirm the validity of the optimal results obtained by Taguchi method. Taguchi experimental design method is very useful to analyze the welding of ferritic stainless steels in MIG welding operation [7]

H. Parametric Optimization of MIG Welding on 316L Austenitic Stainless Steel by Grey-Based Taguchi Method

Nabendu Ghosh*a, Pradip Kumar Palb, Goutam Nandic presents paper on, “Parametric Optimization of MIG Welding on 316L Austenitic Stainless Steel by Grey-Based Taguchi Method” This paper deals with. The best result is obtained for the sample no.3 (Corresponding to current 100 A, flow rate 20 l/min and nozzle to plate distance 15mm). The worst result in tensile testing has been obtained for the sample no. 7 (corresponding to current 124 A, gas flow rate 10 l/min and nozzle to plate distance 15). Current is found to be more significant than gas flow rate and nozzle to plate distance in influencing the strength of the joint. Optimization of the process parameters has been done by using Grey – Taguchi methodology; optimum parametric combination has been determined. The optimal factor setting becomes C1F3S3 (i.e. welding current = 100A, Gas flow rate = 20l/min and Nozzle to plate distance =15mm).[8]

I. Experimental Investigation of MIG Welding for ST-37 Using Design of Experiment

S.Utkarsh1, P. Neel2, Mayank T Mahajan3, P.Jignesh4, R. B.Prajapati5 present paper on,”Experimental Investigation of MIG Welding for ST-37 Using Design of Experiment.” This paper deals with different Levels of input parameters and their effect on Response. When the current is too low the molten metal fails to wet the joint surface and cause lack of fusion. with increasing current the melting rate of the electrode is increases. This is a very important variable in MIG welding, mainly because it determines the type of metal transfer by influencing the rate of drop late transfer across the arc. the arc voltage to be used depends on the base metal thickness, type of joint, electro composition and size, shielding gas composition, welding position, type of weld and other factors the linear rate (express in cm/min or mm/sec) at which the arc moves around along the joint ,termed arc travel speed, affects weld bed size and penetration. with other variables kept constant, there is a certain value of travel speed at which the weld penetration is maximum. At the value of gas flow rate of 10(L/Min) we get better signal to noise ratio as 52.62 and at 10(L/Min) Speed we get maximum ultimate tensile strength of 434.34(N/mm2). It is a least affective variable among four of the parameters [9]

J. Study of the effect of shielding gas composition on the mechanical weld properties of steel ST 37-2 in gas metal arc welding

Mohamad Ebrahimnia a, Massoud Goodarzi a,*, Meisam Nouri b, Mohsen Sheikhi b presents paper on, ”Study of the effect of shielding gas composition on the mechanical weld properties of steel ST 37-2 in gas metal arc welding.” This paper deals with the input parameters are The effect of the shielding gas composition on the weld properties of ST 37-2 in GMAW. Increasing the amount of carbon dioxide leads to decrease in the amount of inclusion and porosity.The volume fraction of acicular ferrite decreases and the volume fraction of Widmanstatten ferrite increases in microstructure with increase of the amount of carbon dioxide.Charpy V-notch energy first increases and then remains constant with increase of the amount of carbon dioxide in the shielding gas.Weld metal hardness decreases due to increase of the amount of CO2 in the shielding gas composition [10]

III. Conclusion of Research Paper

As per literature survey, many authors are working with the Metal inert gas welding process along with the Stainless steel and Aluminum alloy with the different condition and different criteria as like:

- Checking Mechanical properties like Ultimate tensile strength, Hardness & % Elongation
- Micro-structure behavior
- Depth of penetration and Deposition rate
- No researcher work satisfactory on ST35 Carbon steel as a Base Metal.
- Voltage, Wire feed rate & Gas flow rate are still in Lag in Parameters.
- Another region is that to find Mechanical Properties like Hardness, Tensile strength and % Elongation for these parameters.

IV. Experimental Setup

SR. NO.	VOLTAGE (V)	WIRE FEED RATE (M/Min)	GAS FLOW RATE (L/Min)
1	18	2	10
2	18	3	15
3	18	4	20
4	22	2	15
5	22	3	20
6	22	4	10
7	26	2	20
8	26	3	10
9	26	4	15

Taguchi method for design of experiments is best as compare to other method because it can provide simplification of experimentation plan and reduce total number of experimental runs so time and cost can be save concern to manufacturing. So I have used Taguchi Method of DOE With L9 Orthogonal Array.

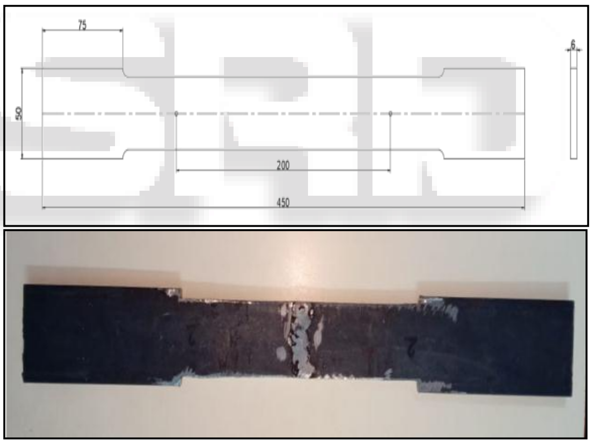
Fig. 4.1: MIG welding machine [22]

In my research method, I have selected Taguchi Methodology for Design of Experiment. This Welding Machine is available at Mechanical Engineering Department Laboratory of Ahmedabad Institute of Technology College, Ahmedabad.

A. *Specimen Preparation for Welding:*

B. *MAG Welded Test Pieces:*

C. *Tensile test Specimen as per ASTM A370:*



V. RESULTS

A. *Summary of ANOVA Calculation for Hardness:*

Source	Df	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Voltage	2	41.7222	20.8611	187.75	0.005	59.27%
Wire Feed rate	2	11.7222	5.8611	52.75	0.019	16.65%
Gas flow rate	2	16.7222	8.3611	75.25	0.013	23.75%
Error	2	0.2222	0.1111			0.31%
Total	8	70.3889				100%

According to main effect plot Hardness is increase with increase in Voltage, with Wire feed rate it is increase at some extent and then constant & with Gas flow rate, it is increase.

B. Summary of ANOVA Calculation for Tensile Strength:

Source	Df	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Voltage	2	296.000	148.000	49.33	0.020	31.22%
Wire Feed rate	2	350.000	175.000	58.33	0.017	36.91%
Gas flow rate	2	296.000	148.000	49.33	0.020	31.22%
Error	2	6.000	3.000			0.63%
Total	8	948.000				100%

According to main effect plot Tensile strength is increase with increase in Voltage, Wire feed rate & Gas flow rate at different rates.

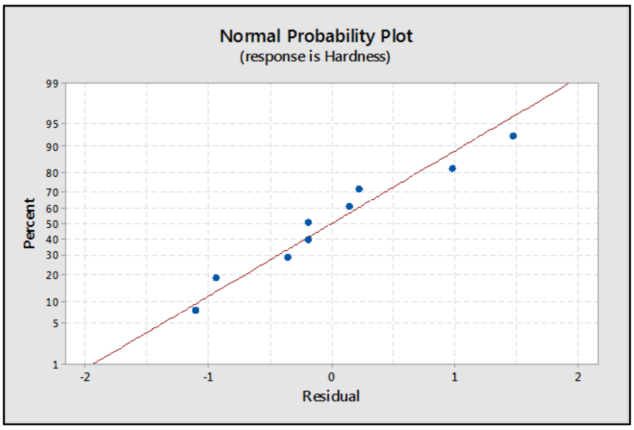
C. Summary of ANOVA Calculation for % Elongation:

Source	Df	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Voltage	2	1.80222	0.90111	26.16	0.037	32.32%
Wire Feed rate	2	2.14889	1.07444	31.19	0.031	38.54%
Gas flow rate	2	1.55556	0.77778	22.58	0.042	27.89%
Error	2	0.06889	0.03444			1.23%
Total	8	5.57556				100%

According to main effect plot % Elongation is increase with increase in Voltage, Wire feed rate & Gas flow rate at different rates.

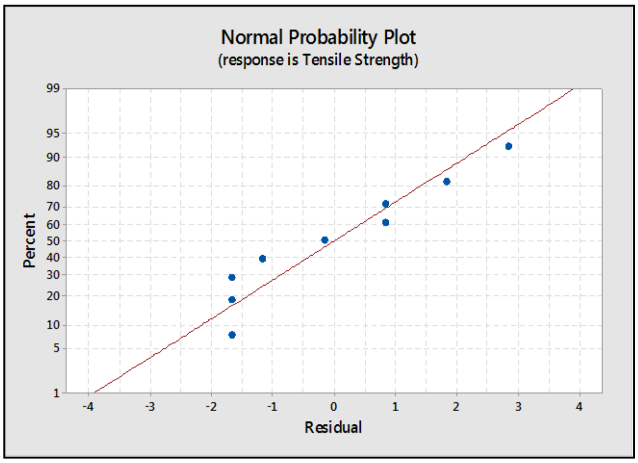
D. Regression Analysis:

Hardness = 60.90 + 0.646 Voltage + 1.167 WFR + 0.3333 GFR



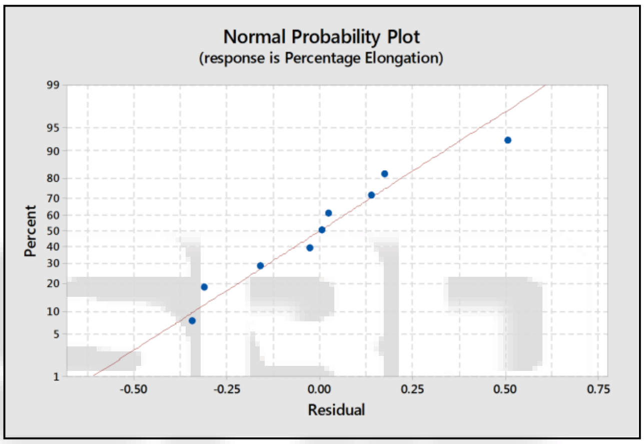
Main effect residual plot for Hardness

Tensile Strength =294.67 + 1.750 Voltage + 7.500 WFR + 1.400 GFR



Main Effect Residual Plot for Tensile Strength

% Elongation = 1.836 + 0.1292 Voltage + 0.567 WFR + 0.1000 GFR



Main effect residual plot for % Elongation

E. Optimization with GRA:

Run Order	Coefficient value of Hardness	Coefficient value of Tensile strength	Coefficient value of % Elongation	Grey relational grade	Grade No.
1	0.333333	0.333333	0.333333	0.333333	9
2	0.473684	0.443038	0.490196	0.468973	7
3	0.6	0.777778	0.862069	0.746616	3
4	0.45	0.466667	0.409836	0.442168	8
5	0.75	0.686275	0.757576	0.731284	4
6	0.473684	0.636364	0.510204	0.540084	6
7	0.9	0.777778	0.714286	0.797355	2
8	0.818182	0.538462	0.757576	0.70474	5
9	1	1	1	1	1

From this optimization technique of Grey relational analysis we have conclude that as per grey relational grade the 9^{TH} combination set is the best set among 9 experiments. The value of Voltage is 26 Volt, WIRE FEED RATE is 4 M/min and GAS Flow rate is 15 L/min.

VI. CONCLUSION

A. Hardness

1) In the Taguchi method, the percentage contribution of Voltage is 59.27%, Wire feed rate is 16.65% and Gas flow rate is 23.75% on Hardness.
2) When we change the values of Input Parameters, its effects on Hardness is as follows:
   Voltage from 18 to 22, Hardness increases at slow rate, but from 22 to 26 V it increase rapidly.
   Wire feed rate from 2 to 3, Hardness increases, but from 3 to 4 M/min it is almost constant.
   Gas flow rate from 10 to 20 L/min Hardness increases linearly.
3) As we can see that here Voltage is most affected Parameter on Hardness and it will followed by Gas flow rate and Wire feed rate.

B. Tensile Strength

1) In the Taguchi method, the percentage contribution of Voltage is 31.22%, Wire feed rate is 36.91% and Gas flow rate is 31.22% on Tensile Strength.
2) When we change the values of Input Parameters, its effects on Tensile Strength is as follows:
   Voltage from 18 to 26, Tensile Strength increases linearly.
   Wire feed rate from 2 to 3, Tensile Strength increases slowly but from 3 to 4 M/min it increases rapidly.
   Gas flow rate from 10 to 20 L/min Tensile Strength increases linearly.
3) As we can see that here Wire feed rate is most affected Parameter on Tensile strength and it will followed by Voltage and Gas flow rate.

C. % Elongation

1) In the Taguchi method, the percentage contribution of Voltage is 32.32%, Wire feed rate is 38.54% and Gas flow rate is 27.89% on % Elongation.
2) When we change the values of Input Parameters, its effects on % Elongation is as follows:
   Voltage from 18 to 22, % Elongation increases very slowly, but from 22-26 V it increases rapidly.
   Wire feed rate from 2 to 3, % Elongation increases rapidly but from 3 to 4 M/min it increases slowly.
   Gas flow rate from 10 to 15 L/min % Elongation increases slowly, but from 15-20 it increases rapidly.
3) As we can see that here Wire feed rate is most affected Parameter on % Elongation and it will followed by Voltage and Gas flow rate.

D. Optimization

From this optimization technique of Grey relational analysis we have conclude that as per grey relational grade the 9^{TH} combination set is the best set among 9 experiments. The value of Voltage is 26 Volt, WIRE FEED RATE is 4 M/min and GAS Flow rate is 15 L/min.

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